STAINLESS STEELS

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By

PERCY H. MILLER

Author of

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PREFACE

At the time of my previous publication, *The Practice of Engineering Estimating*, the use of Stainless Steels had only crossed the threshold of general engineering.

Owing to the lack of reliable data and the fact that it ranked mainly as a specialized subject, it was not included in that work. The last few years, however, have seen a rather rapid evolution in stainless steel and its applications.

Even now, the class of information required by the manager, engineer, draughtsman, and estimator, is not satisfactorily collated within existing text-books.

The author offers this short work in the hope that it will prove of both interest and everyday use to those who contemplate the inclusion of stainless steels within their plant.

A book dealing with a subject which is still in a more or less embryonic state cannot hope to do more than outline the main features of that subject; nevertheless, it is hoped that it will form at least a 'stopgap' during such transitory period.

P. H. M.

DERBY

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A SHORT HISTORY OF THE PROGRESS OF STAINLESS-STEEL PRODUCTION

THE use of stainless steels is comparatively new to the field of engineering, and whilst in the last few years it has rapidly advanced to take its place in many forms, mainly where hitherto great inconvenience and maintenance costs have been the bane of the engineer, due chiefly to stress and corrosion problems, even now there is remarkably little information to be obtained in concise form.

The principal manufacturers of stainless steels are, of course, publishing considerable reliable information concerning the properties and the uses of their own particular brands, but where one has to apply such information to the multitudinous problems constantly confronting the engineer, it is unfortunate, particularly from the time factor point of view, that such a long period has already elapsed without the textbook aid that is available in such a wealth of detail for the more widely known materials.

The lack of reliable information as to the effects upon capital costs when introducing stainless steel within a plant is also very keenly felt by the executive engineer or the estimator. Obviously, if it is proposed to use a metal such as this, then the saving in maintenance costs over a period must be weighed in the balance against capital cost.

In regard to costs, it will obviously be some time yet before really stabilized and reliable price-lists can be compiled for the guidance of users.

This is particularly true, for, as already stated, stainless

steels are of only recent introduction, yet the number of types and qualities is so extensive as to preclude the possibility of embracing them all in any general treatise.

This text, therefore, confines itself to various groups which should suffice for all general requirements.

Stainless steels are now available in all the requisite forms for use in engineering; including castings, forgings, sheets, bars, sections, tubes, &c.

The machining presents a somewhat different set of conditions to those encountered in ordinary-quality steels, and this aspect will be dealt with in a later paragraph.

The welding of stainless steel has also put before the engineer a completely new set of problems, and for a long time was found to be very unsatisfactory, so much so, that it was repeatedly found that the material was no longer corrosion-resisting; this has been designated as 'weld-decay'.

The manufacturers have attacked this problem with quite a good measure of success, and it is now possible to procure special welding qualities in which this defect is more or less eliminated.

Unfortunately, however, it has had a rather adverse effect upon prices, and the best qualities are considerably higher in cost. The question of welding will also be enlarged upon at the appropriate point in the text.

Now, generally speaking, we have two distinct types of stainless steels—Martensitic and Austenitic respectively.

The two types are again split into quite a large number of groups, the former mainly consisting of several grades of plain chromium steels and one or more of the higher chromium steels containing some nickel, about 2 per cent.

The austenitic qualities have a much higher nickel content, whilst the better qualities have proportions of titanium or molybdenum.

In order to avoid prolixity it is proposed to deal with only six classifications of steels in this text, the first two being of the martensitic and the remaining four of the austenitic type. The following table gives the contents and characteristics of these six distinct groups:

	M. 1	*M. 2*	*A. 1*	*A. 2*	*A. 3*	*A. 4*
Type	*Martensitic*	*Martensitic*	*Austenitic*	*Austenitic*	*Austenitic*	*Austenitic*
Brinell No.	200	250	170	180	170	180
Tensile strength. Tons per square inch	50–100	45–65	40–60	40–60	40–60	40–60
Elongation. Per cent.	25	20	50	45	50	50
Reduction of area. Per cent.	55	50	50	50	50	50
Specific gravity	7·72	7·71	7·91	7·91	7·90	7·90
Percentage chromium	13	18	18	18	20	20
Percentage nickel	..	2	8	8	6	6
Percentage titanium	..	..	..	1	..	..
Percentage molybdenum	..	..	..	..	$2\frac{1}{2}$–3	4
Pattern-maker's shrinkage per foot	$\frac{1}{4}''$	$\frac{9}{32}''-\frac{5}{16}''$	$\frac{9}{32}''-\frac{5}{16}''$	$\frac{9}{32}''-\frac{5}{16}''$	$\frac{9}{32}''-\frac{5}{16}''$	$\frac{9}{32}''-\frac{5}{16}''$

NOTE: The quality numbers indicated in the above table do not refer to any references adopted by the various manufacturers, but are for the purpose of reference within this text-book.

In quality A. 2 one manufacturer substituted silicon for titanium with improved results in casting form.

These steels have all more or less subsequently evolved in the order given in the foregoing table.

No. M. 1 was the original chromium steel and was first made about 1913 and 1914, being mainly used in the manufacture of cutlery. It is always possible that future research will find still further modifications by the inclusion of other elements in alloyed steels, but there seems to be very little choice beyond those already successfully applied.

Apart from the elements given in the table, which are of course dealing with stainless steels only, other alloyed steels are on the market containing such elements as vanadium, manganese, cobalt, and tungsten.

The simplest form of alloyed steels contain only three elements, namely iron, carbon, and one other of the various alloying elements specified: this is known as a Ternary steel.

If two of the other alloying elements were included it would be designated as a Quarternary steel, whilst if an alloyed steel contained more than two of the other elements it would be known as a Complex steel.

The latter are often special alloyed steels for use as high-speed cutting-tools.

Referring back to plain chromium steels, the reader is reminded that these were first used much earlier than the class referred to as M. 1, but the chromium content was only in the neighbourhood of 1 per cent.

It was introduced almost solely because of its hardness, and it was not until 1913 that the greatly increased percentage of chromium was added to produce a special steel which was highly resistant to corrosion.

II

MANUFACTURE AND PROPERTIES

The real dividing line between the two main groups is, that the martensitic types are all hardenable steels, whilst the austenitic types are not hardenable.

The martensitic group can all be air-hardened from a temperature range of 950–1,000° C., and, where necessary, can be tempered; a range of steels giving varying tensile strengths of up to 100 tons per square inch, and even over, whilst retaining their ductility is thereby available.

Obviously, therefore, they are of great value for use in highly stressed parts.

This group is also largely used for forgings.

The austenitic group, on the other hand, will have a tensile strength of from 40 to 60 tons only, but a remarkably high ductility. Their greatest asset is the marked resistance to corrosive and chemical action, and some of their main uses will be found in plant for food handling, chemical plant, and the textile industry.

The greatest care has to be taken in the mixing of every 'melt' and is a question of careful refining. Should undesirable matter be allowed to contaminate the 'melt', then electrolytic action may ensue and thereby destroy the corrosion-resisting properties of the steel.

Similarly, this careful grading has to be carried out in every different specification of stainless steel in order that the manufacturers may guarantee that particular specification definitely.

Obviously, if this were not observed, then the whole

principle of applying special specifications to best suit the purpose for which the stainless steel is intended would fail at the outset.

For this reason it is not often possible to include more than a very small proportion of scrap in the furnace, in fact, we might go so far as to say that the use of scrap is eliminated entirely. At least, only scrap which can be guaranteed as being of similar specification to the new 'melt' would be included.

For this reason it will be noted that very low prices are paid for stainless steel scrap, and manufacturers, for the most part, will only entertain scrap from steels which emanated originally from their own foundries.

This is not an unimportant point, as the estimator particularly will do well to remember that when substituting stainless steels for non-ferrous metals, for instance, the allowance for scrap will not credit his costs to anything like the same extent.

The average price of scrap is 12 shillings per cwt.

Reverting to the six groups selected as being indicative of a reasonably full range, let us examine the salient features of each and the uses for which they are most suitable.

M. 1, as already indicated, is used mainly in the manufacture of cutlery and edged tools, its high tensile strength being the chief asset. It is also possible to raise its temperature to extremely high points (say round about 750° C.) without scaling.

Its high tensile strength also makes it suitable for use in components for automobile, aeronautical, and locomotive engineering.

M. 2 is not really a straight chromium stainless steel, but,

as will be seen from the table, has a 2 per cent. content of nickel, whilst the chromium content has also been raised from 13 to 18 per cent.

The straight chromium steels, whilst possessing the excellent qualities described under M. 1, are liable, under excessive conditions, not to remain impervious to corrosion. This, of course, could be overcome by the increased chromium content—for instance, the 18 per cent. content just mentioned—but unfortunately the mechanical strength is impaired, whilst the hardening properties are also destroyed.

The addition of the 2 per cent. nickel content, however, serves to retain the mechanical strength to a large extent, and it is still a hardenable steel, a tensile strength up to 65 tons per square inch being obtained. If greater proportions of nickel were introduced, we should arrive at an austenitic steel not amenable to hardening.

Some of the main uses of M. 2 are to be found in pumps dealing with brine, or water with acid content, valve components, naval work, seaplanes, and the like.

A. 1 can be described as meeting the general specification of true stainless steel. It is particularly useful in the form of thin sheetwork, the surface being suitable for polishing up to remarkable fineness, or in other words, up to 'mirror finish'.

As already intimated, being a member of the austenitic family it cannot be hardened, but its tensile strength can be varied from 40 to 60 tons per square inch.

It is readily amenable to cold working, and can be stamped or soldered.

It is not very useful for welding purposes and unless

heat-treated and water-quenched after hot working, its corrosion-resisting properties will be seriously impaired. This heat-treating and quenching would not, obviously, be very desirable in large work. However, when cold worked, it will be found to have a marked resistance to chemical attack, and for this reason is very widely used for food handling and chemical and dyeing plants. In its mirror-finished condition it is also now widely used in decorative work.

A. 2 is very similar to A. 1, but titanium has been added to the extent of 1 per cent. As explained in the paragraph concerning A. 1: whilst the latter is exceptionally good for thin sheetwork it does not retain its corrosion-resisting properties when hot worked, as in welding.

The titanium, therefore, was added to overcome this defect, and certainly resulted in a stainless steel which could be more or less successfully welded, but the corrosion-resisting qualities still appear to be somewhat impaired.

It does not quite so readily work up to the fine polish of A. 1, although a very good finish is obtainable. However, because of its better resistance to 'weld-decay' it is preferable for use in thicker platework.

A. 3 was introduced as a progressive step to A. 2 in the quest for a steel with greater resistance to some of the more searching corrosive agents and also to still further successfully combat the 'weld-decay' problem. This was obtained by substituting molybdenum in place of the titanium, but in greater quantity, i.e. 2½–3 per cent.

This quality is particularly adaptable for pump-work, centrifugals, or plant handling sulphuric acid, &c. Its

really great virtue lies in the fact that it is resistant against corrosive agents at a wide range of temperatures, up to boiling-point.

A. 4 was introduced because it was discovered that the excellent corrosion-resisting qualities of A. 3 were not definitely maintained after hot working.

The molybdenum content was therefore increased to 4 per cent. and appeared to meet with a measure of success. Unfortunately it is difficult to arrive at any hard and fast rules concerning these corrosion-resisting properties, and in the experience of the author it is not possible to claim definitely that A. 4 is really any advancement upon A. 3; but this can only be determined by actual experiment with the purpose the steel is intended to serve.

III

VARIOUS ELEMENTS USED IN STAINLESS STEELS

It would be well, perhaps, at this point to digress from the main theme in order to discuss briefly the several special elements used in the production of stainless steel.

First, there is the main alloying element of all stainless steels, namely, chromium. Chromium is produced from chrome iron ore, or chromite, and is obtainable by heating equal parts of chromic oxide and aluminium powder, this producing a fused mass of nearly pure chromium.

An electric furnace is used to produce it on a commercial scale, the oxide being heated with carbon; but the metal is almost always contaminated by chromium carbides. A second refining process is therefore essential, and it is placed in the furnace on a bed of lime and chromic oxide. This is followed by a further refinement with a double oxide of chromium and calcium. This should result in pure chromium, grey in colour and extremely hard.

Contamination with carbides is to be avoided, as this would result in increasing the hardness to an undesirable extent.

Chromium is noted for its abnormally high resistance to heat, high tensile strength even at high temperatures, resistance to corrosive agents, and absence of scaling at temperatures even in the neighbourhood of 1,000° C.

The electro-deposition of chromium for plating work is now extensively used, being particularly suitable on account of its hardness. For this reason, and also on the

score of price, it is much more extensively used for decorative work than pure stainless steels, which, by comparison, are much more liable to surface scratching.

The specific gravity of chromium is 7·14.

The next alloying element to be considered is nickel. This can be obtained in malleable ingots suitable for rolling, drawing, &c. In its pure condition it is not suitable for such working and has to be re-melted and deoxidized.

It is possessed of great strength, good appearance (it can be polished to a great degree of fineness), and corrosion resistance. It can be alloyed with a great variety of metals, both ferrous and non-ferrous. The nickel produced by the Mond process is accepted as possessing the greatest degree of purity (almost 100 per cent.) and is guaranteed to be free of cobalt.

The colour of the material is silver-white. It is used extensively in coinage, whilst its value in the production of stainless steels has already been emphasized.

The specific gravity is 8·69 as cast and 8·87 for rolled metal. About 90 per cent. of the world's supply of nickel emanates from Ontario, Canada.

The third is titanium, which is often considered to be amongst the rare metals, but this is not by any means true, and it is, in fact, fairly cheap and plentiful. It is normally contaminated with oxide or nitride, owing to its remarkable affinity for oxygen and nitrogen. The pure metal is white, the physical properties closely resembling steel.

In the steel industry it has been used, in the form of ferro-titanium, to act as a deoxidizer and denitrogenizer, resulting in a much cleaner and sounder metal, and, as already intimated, improving the properties.

Lastly there is molybdenum, which we find specified in grades A. 3 and A. 4.

This is most definitely fairly rare and expensive, being about 4*s*. 6*d*. per lb. It is a silver-white metal and closely resembles chromium.

When used as an element in steel it goes into solid solution in the ferrite, thereby adding to the strength.

It may also be present as a combined carbide. Its effect, therefore, is to increase both the strength and hardness, and it certainly prevents inter-crystalline corrosion.

The bulk of the world's production of molybdenum emanates from Australasia.

IV

MATERIALS PRICE-LIST

In the pages immediately following will be found weight and price tables of the several groups with which we are concerned, and dealing with the various forms of material as purchased from the suppliers.

These tables are prefaced with an index table to the several groups. As the main manufacturers all have their own trade references to each type, this index table forms a key to such references in order to clarify the position for the reader when making definite selections from competitive tenders.

Supplier (Messrs.)	*M. 1*	*M. 2*	*A. 1*	*A. 2*	*A. 3*	*A. 4*
Firth Brown	F.G.	S. 80	F.S.T.	F.D.P.	F.M.L.	F.M.B.
Bayley	Brearley	Twoscore	Anka	Weldanka	B.B. 2K	B.B. 4K
Osborn	R.P.I.	D.N.	Evershyne B.S.	Weldshyne	Weldshyne E.W.	Weldshyne E.W. 4
Hadfields	..	..	Era. C.R.1	Era. C.R. 1S.	Era. C.R. 4	Era. C.R. 4S.
Fox	Silver Fox 18	Silver Fox 18	Silver Fox 20	Silver Fox 22	..	Silver Fox 24
Allen	..	..	Maxilvry	Maxilvry A.W.P.	..	Maxilvry A.M.

The foregoing table only covers most of the English suppliers. It is not proposed to tabulate the suppliers on the Continent.

In passing, however, it is mentioned that continental supplies are not likely to show any saving in cost, as although at present market-rates the F.O.B. price may show a marked reduction on home prices, by the time duty, carriage, &c., has been met, there will not be any great difference in overall cost.

It will be fully realized that all prices quoted in the following tables can only be guaranteed as at the time of this publication.

Admittedly, it could logically be expected that with the use of stainless steels becoming more general and widespread, manufacturers would be sufficiently well insured as to future prospects to make some determined onslaught on present seemingly high prices. It is pointed out, however, that the past few years have been spent by the manufacturers in very intensive research, and such research must needs still be pursued. The manufacture of stainless steels, therefore, is highly specialized and demand is now probably exceeding immediate supplies.

Furthermore, at this date, the rearmament programme is tending to cause prices to harden somewhat, but all things considered, it is reasonably safe to assume that the prices indicated herein can be used for a considerable period without undue misgivings.

In any event, a comparison between market lists of materials generally at this date and the equivalent lists at the date of using these tables should enable the reader to make the necessary adjustments.

For this purpose the following rates were used to form the basis of the prices quoted:

	£	s.	d.	
Pig iron (Derby No. 3)	4	6	0	per ton
Steel billets	7	15	0	,, ,,
Ferro-silicon	12	0	0	,, ,,
Electrolytic copper	48	0	0	,, ,,
Metallic chromium		2	5	,, lb.
Nickel	200	0	0	,, ton
Molybdenum		4	6	,, lb.
Titanium			9	,, lb.

Firstly, there will be found tables of sheets from 30 I.S.W.G. thick to ½ inch thick. These are all based on hot rolled descaled quality and at the end of the several relevant tables will be found a list of extras which will be more or less stable.

SURFACE FINISHES

Although following the tables of sheets the additional cost is indicated of the extras entailed in several grades of finishes, it must be borne in mind that such finishes cannot necessarily be applied to every quality of sheet.

Whilst a plain chromium steel (M. 1 and M. 2) gives a ground super-polish, others cannot be ground optically owing to the fact of their non-magnetic properties.

Quite a good surface finish can, however, be made with a plain 18/8 chromium austenitic stainless steel, although in its fully heat-treated condition it is non-magnetic.

The other grades in the austenitic group, whilst normally non-magnetic, may be found to become feebly magnetic with the varying addition of the other alloying elements.

There is no definite ratio as to the sympathy between corrosion-resisting properties and non-magnetic properties however, as when the added elements are present the magnetic properties can vary with very slight differences in composition.

The method of obtaining the surface polishes referred to above is dealt with on p. 44.

HOT ROLLED DESCALED SHEETS

Quality M. 1

Thickness	*Weight sq. ft. lb.*	*Price per lb.*	*Thickness*	*Weight sq. ft. lb.*	*Price per lb.*	*Thickness*	*Weight sq. ft. lb.*	*Price per lb.*
		s. d.			*s. d.*			*s. d.*
30 gauge	0·482	3 7	18 gauge	1·94	1 7	7 gauge	7·06	1 4
29 ,,	0·527	3 5	17 ,,	2·24	,,	6 ,,	7·70	,,
28 ,,	0·566	3 4	16 ,,	2·57	1 6	5 ,,	8·50	1 3
27 ,,	0·643	,,	15 ,,	2·89	,,	4 ,,	9·31	,,
26 ,,	0·724	3 3	14 ,,	3·21	,,	3 ,,	10·09	1 2
25 ,,	0·804	3 0	13 ,,	3·66	,,	2 ,,	11·00	,,
24 ,,	0·884	2 3	12 ,,	4·17	1 5	1 ,,	12·00	,,
23 ,,	0·965	2 1	11 ,,	4·65	,,	$\frac{5}{16}$ inch	12·48	,,
22 ,,	1·13	1 9	10 ,,	5·13	,,	$\frac{3}{8}$,,	15·04	1 1
21 ,,	1·28	1 8	9 ,,	5·77	,,	$\frac{7}{16}$,,	17·55	,,
20 ,,	1·44	,,	8 ,,	6·41	1 4	$\frac{1}{2}$,,	20·00	1 0½
19 ,,	1·60	1 7						

Quality M. 2

Thickness	*Weight sq. ft. lb.*	*Price per lb.*	*Thickness*	*Weight sq. ft. lb.*	*Price per lb.*	*Thickness*	*Weight sq. ft. lb.*	*Price per lb.*
		s. d.			*s. d.*			*s. d.*
30 gauge	0·482	4 0	18 gauge	1·94	1 9	7 gauge	7·05	1 6
29 ,,	0·527	3 10	17 ,,	2·23	,,	6 ,,	7·68	,,
28 ,,	0·566	3 9	16 ,,	2·56	1 8	5 ,,	8·48	1 5
27 ,,	0·643	,,	15 ,,	2·88	,,	4 ,,	9·29	,,
26 ,,	0·724	,,	14 ,,	3·20	,,	3 ,,	10·07	1 4
25 ,,	0·804	3 4	13 ,,	3·65	,,	2 ,,	10·99	,,
24 ,,	0·884	2 6	12 ,,	4·16	1 7	1 ,,	11·98	,,
23 ,,	0·965	2 4	11 ,,	4·64	,,	$\frac{5}{16}$ inch	12·45	1 3
22 ,,	1·13	2 0	10 ,,	5·12	,,	$\frac{3}{8}$,,	14·96	,,
21 ,,	1·28	1 11	9 ,,	5·76	,,	$\frac{7}{16}$,,	17·54	,,
20 ,,	1·44	1 10	8 ,,	6·40	1 6	$\frac{1}{2}$,,	19·95	1 2
19 ,,	1·60	,,						

HOT ROLLED DESCALED SHEETS (*cont.*)

Quality A.1

Thickness	*Weight sq. ft. lb.*	*Price per lb.*	*Thickness*	*Weight sq. ft. lb.*	*Price per lb.*	*Thickness*	*Weight sq. ft. lb.*	*Price per lb.*
		s. d.			*s. d.*			*s. d.*
30 gauge	0·493	4 3	18 gauge	1·99	1 10	7 gauge	7·23	1 7
29 ,,	0·538	4 1	17 ,,	2·30	,,	6 ,,	7·89	,,
28 ,,	0·575	4 0	16 ,,	2·63	1 9	5 ,,	8·71	1 6
27 ,,	0·657	,,	15 ,,	2·96	,,	4 ,,	9·53	,,
26 ,,	0·739	,,	14 ,,	3·29	,,	3 ,,	10·35	1 5
25 ,,	0·822	3 6	13 ,,	3·75	,,	2 ,,	11·30	,,
24 ,,	0·904	2 8	12 ,,	4·27	1 8	1 ,,	12·30	,,
23 ,,	0·986	2 6	11 ,,	4·77	,,	$\frac{5}{16}$ inch	12·80	1 4
22 ,,	1·15	2 1	10 ,,	5·26	,,	$\frac{3}{8}$,,	15·40	,,
21 ,,	1·31	2 0	9 ,,	5·92	,,	$\frac{7}{16}$,,	18·00	,,
20 ,,	1·48	1 11	8 ,,	6·57	1 7	$\frac{1}{2}$,,	20·50	1 3
19 ,,	1·64	,,						

Quality A.2

Thickness	*Weight sq. ft. lb.*	*Price per lb.*	*Thickness*	*Weight sq. ft. lb.*	*Price per lb.*	*Thickness*	*Weight sq. ft. lb.*	*Price per lb.*
		s. d.			*s. d.*			*s. d.*
30 gauge	0·493	4 4	18 gauge	1·99	1 11	7 gauge	7·23	1 8
29 ,,	0·538	4 2	17 ,,	2·30	,,	6 ,,	7·89	,,
28 ,,	0·575	4 1	16 ,,	2·63	1 10	5 ,,	8·71	1 7
27 ,,	0·657	,,	15 ,,	2·96	,,	4 ,,	9·53	,,
26 ,,	0·739	,,	14 ,,	3·29	,,	3 ,,	10·35	1 6
25 ,,	0·822	3 7	13 ,,	3·75	,,	2 ,,	11·30	,,
24 ,,	0·904	2 9	12 ,,	4·27	1 9	1 ,,	12·30	,,
23 ,,	0·986	2 7	11 ,,	4·77	,,	$\frac{5}{16}$ inch	12·80	1 5
22 ,,	1·15	2 2	10 ,,	5·26	,,	$\frac{3}{8}$,,	15·40	,,
21 ,,	1·31	2 1	9 ,,	5·92	,,	$\frac{7}{16}$,,	18·00	,,
20 ,,	1·48	2 0	8 ,,	6·57	1 8	$\frac{1}{2}$,,	20·50	1 4
19 ,,	1·64	,,						

HOT ROLLED DESCALED SHEETS (*cont.*)

Quality A.3

Thickness	*Weight sq. ft. lb.*	*Price per lb.*	*Thickness*	*Weight sq. ft. lb.*	*Price per lb.*	*Thickness*	*Weight sq. ft. lb.*	*Price per lb.*
		s. d.			*s. d.*			*s. d.*
30 gauge	0·493	4 8	18 gauge	1·99	2 3	7 gauge	7·21	2 0
29 ,,	0·538	4 6	17 ,,	2·30	,,	6 ,,	7·87	,,
28 ,,	0·575	4 5	16 ,,	2·63	2 2	5 ,,	8·69	1 11
27 ,,	0·657	,,	15 ,,	2·96	,,	4 ,,	9·51	,,
26 ,,	0·739	,,	14 ,,	3·29	,,	3 ,,	10·32	1 10
25 ,,	0·822	3 11	13 ,,	3·74	,,	2 ,,	11·27	,,
24 ,,	0·904	3 1	12 ,,	4·26	2 1	1 ,,	12·27	,,
23 ,,	0·983	2 11	11 ,,	4·76	,,	$\frac{5}{16}$ inch	12·77	1 9
22 ,,	1·15	2 6	10 ,,	5·25	,,	$\frac{3}{8}$,,	15·37	,,
21 ,,	1·31	,,	9 ,,	5·91	,,	$\frac{7}{16}$,,	17·95	,,
20 ,,	1·48	2 4	8 ,,	6·56	2 0	$\frac{1}{2}$,,	20·45	1 8
19 ,,	1·64	,,						

Quality A.4

Thickness	*Weight sq. ft. lb.*	*Price per lb.*	*Thickness*	*Weight sq. ft. lb.*	*Price per lb.*	*Thickness*	*Weight sq. ft. lb.*	*Price per lb.*
		s. d.			*s. d.*			*s. d.*
30 gauge	0·493	5 2	18 gauge	1·99	2 9	7 gauge	7·21	2 6
29 ,,	0·538	5 0	17 ,,	2·30	,,	6 ,,	7·87	,,
28 ,,	0·575	4 11	16 ,,	2·63	2 8	5 ,,	8·69	2 5
27 ,,	0·657	,,	15 ,,	2·96	,,	4 ,,	9·51	,,
26 ,,	0·739	,,	14 ,,	3·29	,,	3 ,,	10·32	2 4
25 ,,	0·822	4 5	13 ,,	3·74	,,	2 ,,	11·27	,,
24 ,,	0·904	3 7	12 ,,	4·26	2 7	1 ,,	12·27	,,
23 ,,	0·983	3 5	11 ,,	4·76	,,	$\frac{5}{16}$ inch	12·77	2 3
22 ,,	1·15	3 0	10 ,,	5·25	,,	$\frac{3}{8}$,,	15·37	,,
21 ,,	1·31	2 11	9 ,,	5·91	,,	$\frac{7}{16}$,,	17·95	,,
20 ,,	1·48	2 10	8 ,,	6·56	2 6	$\frac{1}{2}$,,	20·45	2 2
19 ,,	1·64	,,						

EXTRAS APPLICABLE TO ALL THE FOREGOING QUALITIES OF SHEETS

1. For cold rolled quality . . . . add 15%.
2. For dull polished ONE side only . . . . add 5%.
3. „ „ „ TWO sides . . . . add 20%.
4. „ „ „ ONE side and bright polished on OTHER . . . add 25%.
5. „ bright „ ONE side only . . . . add 10%.
6. „ „ „ TWO sides . . . . add 35%.
7. „ super mirror finish ONE side only . . . . . . add 20%.
8. „ „ „ „ TWO sides . . . . add 50%.
9. Extras due to non-standard lengths and widths to be obtained from makers if possible, but bear in mind that saving in fabrication costs by using special sizes of sheets may not always counterbalance the increased cost of materials.

FLAT BARS

A. 1 Quality: Descaled

Weights in lb. per foot run. Prices per lb.

Width	3/16"		1/4"		5/16"		3/8"		7/16"		1/2"		5/8"	
Inches	*Weight*	*Price*	*Weight*	*Price*	*Weight*	*Price*	*Weight*	*Price*	*Weight*	*Price*	*Weight*	*Price*	*Weight*	*Price*
		s. d.		*s. d.*		*s. d.*		*s. d.*		*s. d.*		*s. d.*		*s. d.*
1/2	0·31	2 1	0·42	2 1	0·53	2 0	0·64	2 0						
5/8	0·39	„	0·53	2 0	0·66	„	0·79	„	0·93	2 0	1·06	1 11		
3/4	0·47	„	0·64	„	0·80	„	0·95	„	1·11	1 11	1·28	„	1·59	1 11
7/8	0·55	2 0	0·75	„	0·93	„	1·11	1 11	1·30	„	1·49	„	1·86	„
1	0·63	„	0·85	„	1·06	1 11	1·28	„	1·49	„	1·70	„	2·13	1 10
1 1/8	0·71	„	0·96	„	1·20	„	1·43	„	1·67	„	1·92	„	2·39	„
1 1/4	0·79	„	1·06	1 11	1·33	„	1·59	„	1·86	„	2·13	1 10	2·66	„
1 3/8	0·87	„	1·17	„	1·46	„	1·75	„	2·05	1 10	2·34	„	2·92	„
1 1/2	0·95	„	1·28	„	1·59	„	1·91	„	2·23	„	2·55	„	3·19	„
1 3/4	1·12	1 11	1·49	„	1·86	„	2·23	1 10	2·60	„	2·98	„	3·72	1 9
2	1·28	„	1·70	„	2·13	1 10	2·55	„	2·98	„	3·40	1 9	4·25	„
2 1/4	1·44	„	1·91	„	2·39	„	2·87	„	3·35	1 9	3·83	„	4·78	„
2 1/2	1·59	„	2·13	1 10	2·66	„	3·19	„	3·72	„	4·25	„	5·31	„
2 3/4	1·75	„	2·34	„	2·92	„	3·51	1 9	4·09	„	4·68	„	5·84	„
3	1·91	„	2·55	„	3·19	„	3·83	„	4·46	„	5·10	„	6·38	„
3 1/4	2·07	1 10	2·76	„	3·45	1 9	4·14	„	4·84	„	5·53	„	6·91	1 8
3 1/2	2·23	„	2·98	„	3·72	„	4·46	„	5·20	„	5·95	„	7·44	„
4	2·55	„	3·40	1 9	4·25	„	5·10	„	5·95	„	6·80	1 8	8·50	„
4 1/2	2·87	„	3·83	„	4·78	„	5·74	„	6·70	1 8	7·65	„	9·57	„
5	3·19	1 9	4·25	„	5·31	„	6·38	„	7·44	„	8·50	„	10·63	„
5 1/2	3·51	„	4·68	„	5·84	„	7·01	1 8	8·18	„	9·35	„	11·69	„
6	3·83	„	5·10	„	6·38	„	7·65	„	8·92	„	10·20	„	12·75	„
7	4·47	„	5·95	„	7·44	1 8	8·93	„	10·41	„	11·90	„	14·88	„
8	5·10	„	6·80	1 8	8·50	„	10·20	„	11·90	„	13·60	„	17·00	„
9	5·74	„	7·65	„	9·56	„	11·48	„	13·39	„	15·30	„	19·11	„
10	6·37	„	8·50	„	10·63	„	12·75	„	14·88	„	17·00	„	21·25	„
11	7·00	1 8	9·35	„	11·69	„	14·03	„	16·36	„	18·70	„	23·37	„
12	7·65	„	10·20	„	12·75	„	15·30	„	17·85	„	20·40	„	25·50	1 7
14	8·91	„	11·90	„	14·88	„	17·85	„	20·83	„	23·80	„	29·75	„
16	10·19	„	13·60	„	17·00	„	20·40	„	23·80	„	27·20	1 7	34·00	„
18	11·45	„	15·30	„	19·13	„	22·95	„	26·78	1 7	30·60	„	38·30	„

FLAT BARS (*cont.*)

Weights in lb. per foot run. Prices per lb.

Width	¾"		⅞"		1"		1¼"		1½"		1¾"	
Inches	*Weight*	*Price*	*Weight*	*Price*	*Weight*	*Price*	*Weight*	*Price*	*Weight*	*Price*	*Weight*	*Price*
		s. d.		*s. d.*		*s. d.*		*s. d.*		*s. d.*		*s. d.*
1	2·55	1 10										
1⅛	2·87	,,										
1¼	3·19	,,	3·72	1 9	4·25	1 9						
1⅜	3·51	1 9	4·09	,,	4·68	,,						
1½	3·83	,,	4·44	,,	5·10	,,	6·38	1 9				
1¾	4·46	,,	5·21	,,	5·95	,,	7·44	1 8	8·93	1 8		
2	5·10	,,	5·95	,,	6·80	1 8	8·50	,,	10·20	,,		
2¼	5·74	,,	6·69	1 8	7·65	,,	9·56	,,	11·48	,,		
2½	6·38	,,	7·44	,,	8·50	,,	10·63	,,	12·75	,,	14·88	1 8
2¾	7·01	1 8	8·18	,,	9·35	,,	11·69	,,	14·03	,,	16·37	,,
3	7·65	,,	8·93	,,	10·20	,,	12·75	,,	15·30	,,	17·85	,,
3¼	8·29	,,	9·67	,,	11·05	,,	13·81	,,	16·58	,,	19·33	,,
3½	8·93	,,	10·41	,,	11·90	,,	14·88	,,	17·85	,,	20·83	,,
4	10·20	,,	11·90	,,	13·60	,,	17·00	,,	20·40	,,	23·80	,,
4½	11·48	,,	13·39	,,	15·30	,,	19·13	,,	22·96	,,	26·78	1 7
5	12·75	,,	14·88	,,	17·00	,,	21·25	,,	25·50	,,	29·75	,,
5½	14·03	,,	16·36	,,	18·70	,,	23·36	,,	28·06	1 7	32·72	,,
6	15·30	,,	17·85	,,	20·40	,,	25·50	,,	30·60	,,	35·70	,,
7	17·85	,,	20·83	,,	23·80	,,	29·75	1 7	35·70	,,	41·66	,,
8	20·40	,,	23·80	,,	27·20	1 7	34·00	,,	40·80	,,	47·60	,,
9	22·95	,,	26·77	1 7	30·60	,,	38·26	,,	45·90	,,	53·55	,,
10	25·50	1 7	29·75	,,	34·00	,,	42·50	,,	51·00	,,	59·60	,,
11	28·05	,,	32·72	,,	37·40	,,	46·74	,,	56·10	,,	65·44	,,
12	30·60	,,	35·70	,,	40·80	,,	51·00	,,	61·20	,,	71·40	,,
14	35·70	,,	41·65	,,	47·60	,,	59·50	,,	71·40	,,	83·30	,,
16	40·80	,,	47·60	,,	54·40	,,	68·00	,,	81·60	,,	95·20	,,
18	45·90	,,	53·55	,,	61·20	,,	76·60	,,	91·80	,,	107·10	,,

NOTE: *Deduct* from above prices to cover *Quality M. 1* . . 15%.
,, ,, ,, ,, ,, ,, ,, *M. 2* . . 5%.
Add to ,, ,, ,, ,, ,, *A. 2* . . 5%.
,, ,, ,, ,, ,, ,, ,, *A. 3* . . 25%.
,, ,, ,, ,, ,, ,, ,, *A. 4* . . 50%.

EXTRA: For other finishes take same percentages as given for sheets.

EXTRA: For cutting into straight lengths will be charged at 10% on all above prices.

STAINLESS-STEEL ANGLE-SECTIONS

Prices per foot run

Section in inches	*Quality A. 1*				*Quality A. 2*			
	Radiused corners		*Square corners*		*Radiused corners*		*Square corners*	
	s.	*d.*	*s.*	*d.*	*s.*	*d.*	*s.*	*d.*
$1 \times 1 \times 12$ gauge	2	5	2	9	2	9	3	2
$1 \times 1 \times \frac{1}{8}$	2	7	3	0	3	0	3	6
$1 \times 1 \times 10$ gauge	2	9	3	2	3	2	3	8
$1 \times 1 \times \frac{3}{16}$	4	2	4	9	4	9	5	6
$1\frac{1}{4} \times 1\frac{1}{4} \times 12$ gauge	2	10	3	3	3	3	3	9
$1\frac{1}{4} \times 1\frac{1}{4} \times \frac{1}{8}$	3	1	3	6	3	6	4	0
$1\frac{1}{4} \times 1\frac{1}{4} \times 10$ gauge	3	2	3	8	3	8	4	3
$1\frac{1}{4} \times 1\frac{1}{4} \times \frac{3}{16}$	4	10	5	7	5	7	6	5
$1\frac{1}{2} \times 1\frac{1}{2} \times \frac{1}{8}$	3	5	3	11	3	11	4	6
$1\frac{1}{2} \times 1\frac{1}{2} \times 10$ gauge	3	7	4	2	4	2	4	9
$1\frac{1}{2} \times 1\frac{1}{2} \times \frac{3}{16}$	5	6	6	3	6	3	7	2
$2 \times 2 \times 10$ gauge	5	0	5	9	5	9	6	7
$2 \times 2 \times \frac{3}{16}$	7	0	8	0	8	0	9	2
$2 \times 2 \times \frac{1}{4}$	8	6	9	9	9	9	11	0

Prices are for fair specifications.
For small lots add 10 to 20%.
„ cutting to exact length add 5%.
„ polishing one side add 20%.

NOTE: The above table allows for softened, straightened, and finally descaled quality bars.

Only sizes up to 2× 2-inch section are included, as above this size it would be much cheaper to weld up flat bars into the desired sections. At the present time it would be most difficult to find a supplier willing or able to offer the larger sizes.

The same remark applies to tee sections and channels, and for this reason tables of these are not included.

STAINLESS-STEEL BARS

A. 1 Quality: Black Finish

Diam. Inches	*Round bar* *Weight per ft. lb.*	*Round bar* *Price per lb.*	*Square bar* *Weight per ft. lb.*	*Square bar* *Price per lb.*	*Hexagon bar* *Weight per ft. lb.*	*Hexagon bar* *Price per lb.*
		s. d.		*s. d.*		*s. d.*
1	2·670	1 5	3·40	1 6	2·87	1 6
1⅛	3·380	,,	4·32	,,	3·64	,,
1¼	4·172	,,	5·32	,,	4·48	,,
1⅜	5·050	,,	6·44	,,	5·44	,,
1½	6·008	1 4	7·75	1 5	6·46	1 5
1⅝	7·060	,,	9·00	,,	7·60	,,
1¾	8·178	,,	10·43	,,	8·81	,,
1⅞	9·390	,,	11·97	,,	10·11	,,
2	10·681	,,	13·62	,,	11·50	,,
2⅛	12·060	,,	15·40	,,	13·00	,,
2¼	13·520	,,	17·25	,,	14·55	,,
2⅜	15·060	,,	19·20	,,	16·22	,,
2½	16·690	,,	21·28	,,	17·95	,,
2⅝	18·400	,,	23·45	,,	19·82	,,
2¾	20·190	1 3	25·75	1 4	21·75	1 4
2⅞	22·070	,,	28·10	,,	23·80	,,
3	24·030	,,	30·64	,,	25·90	,,
3¼	28·210	,,	36·00	,,	30·20	,,
3½	32·710	,,	41·70	,,	35·25	,,
3¾	37·550	,,	47·90	,,	40·00	,,
4	42·730	,,	54·50	,,	46·00	,,
4½	54·070	,,	69·00	,,	58·60	,,
5	66·760	,,	85·20	,,	71·90	,,
5½	80·780	,,	103·10	,,	87·00	,,
6	96·130	,,	122·50	,,	103·20	,,

HEXAGON BARS: The sizes quoted above are for bars measured across the flats.

EXTRA: Cutting into straight lengths will be charged at 10% on the above prices.

OTHER QUALITIES:

Deduct from above prices to cover *Quality*	*M. 1*	20%.
,, ,, ,, ,, ,, ,,	*M. 2*	7½%.
Add to ,, ,, ,, ,,	*A. 2*	5%.
,, ,, ,, ,, ,,	*A. 3*	25%.
,, ,, ,, ,, ,,	*A. 4*	40%.

STAINLESS STEEL ROUND ROD HARDENED AND POLISHED CONDITION

Equal to Quality A. 1

Size	*Weight per ft. lb.*	*Price per lb.*	*Weight per ft. lb.*	*Price per 100 ft.*
		s. d.		£ *s. d.*
18 gauge	0·0053	3 10	0·53	1 10½
1/16 inch	0·0104	3 9	1·04	3 11
5/64 ,,	0·0163	3 8	1·63	6 0
3/32 ,,	0·0234	3 7	2·34	8 4
12 gauge	0·0276	3 3	2·76	9 0
7/64 inch	0·0318	3 2	3·18	10 0
1/8 ,,	0·0417	3 1	4·17	12 9
5/32 ,,	0·065	3 0	6·50	19 6
3/16 ,,	0·094	2 3	9·40	1 1 2
7/32 ,,	0·127	2 2	12·70	1 7 6
1/4 ,,	0·167	2 2	16·70	1 16 3
5/16 ,,	0·261	2 0	26·10	2 12 2
3/8 ,,	0·375	2 0	37·50	3 15 0
7/16 ,,	0·511	2 0	51·10	5 2 2
1/2 ,,	0·667	2 0	66·70	6 13 2
9/16 ,,	0·845	2 0	84·50	8 9 0
5/8 ,,	1·042	2 0	104·20	10 8 4
3/4 ,,	1·500	1 11	150·00	14 8 0
7/8 ,,	2·042	1 10	204·20	18 14 0
1 ,,	2·670	1 10	267·00	24 10 0

NOTE. Usually supplied in lengths 6 ft. and 8 ft. long, but the smaller gauges can be supplied in rolls.

If cut into straight lengths, however, there will be an extra charge of 5% on above prices.

If required in finally softened and descaled condition, all rates per lb. can be taken at 1*d.* extra over above prices.

GENERAL EXTRAS.

For small quantities:

	28 lb. and less than 1 cwt.	14 lb. and less than 28 lb.	7 lb. and less than 14 lb.	Less than 7 lb.
Plus per lb.	1*d.*	2*d.*	4*d.*	8*d.*

V

CASTINGS

THE various grades of stainless steels are now readily obtainable in the form of castings. Much research has been expended in arriving at the present standard and each variety of casting has presented its own peculiar difficulties.

Methods of casting in these alloyed steels are not by any means synonymous with the previously accepted standard methods of casting in ordinary carbon steels. In fact, where certain castings have been attempted in stainless steels along the normal lines of approach, sound castings were found to be impossible and unconventional modifications in the method of moulding were found to be more successful.

There is no doubt, of course, that the presence of nickel, chromium, molybdenum, &c., all tend to have a beneficial effect in that it is bound to raise the ratio of the yield-point to the maximum stress, whereas in ordinary carbon steels this is very low.

The tensile strength is also distinctly superior in stainless steels, and engineers should be able to take this fact into consideration when designing castings, as it may be possible to effect savings in the matter of weight without any sacrifice in the factor of safety.

This is a dually important point, inasmuch that, owing to the higher cost of stainless steels, the saving in weight is definitely desirable if finished costs are not to be prohibitive, and also it may mean that castings may become

possible where hitherto they have been avoided on the score of excessive weight.

After all, whilst recognizing the fact that welded fabrications are rapidly coming to the forefront in engineering, and in many instances very rightly so, in choosing stainless steel the engineer has been actuated by a different set of conditions, viz. corrosion or high temperature troubles, and a casting may very possibly be the easiest method of approach.

By adding nickel to steel castings, the toughness is greatly increased, the grain is refined, whilst they are much more amenable to heat-treatment. This naturally improves the mechanical properties, and taking into consideration that such heat-treatment has greater penetrating powers in these castings, even to the centre of thick sections, the improved characteristics are obtained more uniformly throughout the entire structure, and furthermore the castings can be improved from a founding point of view if the correct methods are adopted.

Steels with a nickel and chromium content have already found a very extensive use in armaments on account of this toughness and also because of their remarkable resistance to sudden impacts. Also, it is rapidly taking its place in other industries due to its corrosion-resisting properties.

It is also worthy of note that the toughness referred to above is still retained at low temperatures, whereas carbon steels are recognized as becoming brittle at lower temperatures.

In casting stainless steels it must be remembered that the co-efficient of expansion is greater than in ordinary steels. Provision for this must be made in the patterns.

The contraction is about 50 per cent. greater than that of mild steel.

An approximation of the cost of stainless-steel castings is indicated below, but as the prices will vary considerably according to specification, intricacy of design, and sizes, it would be well, wherever possible, to submit the inquiry to the manufacturer.

General small castings	@ 2*s*. 0*d*. per lb.
Small intricate castings	@ 2*s*. 6*d*. „
Medium castings	@ 1*s*. 9*d*. „
Heavy castings	@ 1*s*. 3*d*. „

These prices are for castings in quality equivalent to A. 2. All prices are for castings only, unmachined.

VI

FORGINGS

THE martensitic group is eminently suitable for forgings, whilst the chromium-nickel austenitic (No. A. 1) can also be widely used for this purpose.

Generally speaking, forging may be commenced in the neighbourhood of 1,200° C., but 950° C. should be regarded as the definite minimum. These steels are all air-hardening, but should be allowed to cool slowly after hot working.

It is a good plan to place the forgings into a bed of lime, or, if practicable, it is even better to place them in a furnace at about 700° C. withdrawing them when becoming magnetically affected.

An indication of price is very difficult in view of the multitudinous forms and specifications, but for reasonably heavy forgings the price should approximate to 1*s.* 6*d.* per lb. unmachined.

VII

MACHINING

A PRECONCEIVED idea appears to have been prevalent that the machining of stainless steels offers the utmost difficulty, but now that it is becoming more widely used, this impression is gradually becoming eradicated.

Admittedly, a new set of conditions is presented to the machinist, but by adopting the correct methods of approach, no undue troubles need be encountered.

The first essential is to have cutting-tools of a suitable grade and there are now on the market high-speed steels which are quite capable of handling stainless steels with relative ease.

The machinist can do much to help himself by always observing a few elementary precautions. Firstly, his machine must be definitely rigid, chatter of any kind is absolutely detrimental.

Secondly, assuming he has been supplied with the correct quality of tool, the cutting-edge must be kept keen.

Furthermore, having started a cut, it must, whenever possible, be completed without restarting. The correct angle must be observed and lastly, the essential rule which perhaps embraces all others is, work-hardening must be avoided most definitely.

It is this tendency to rapid work-hardening that causes the machining difficulties rather than the Brinell hardness of the metal.

Work-hardening can result in a variety of ways. For instance, it is very easily caused by permitting the tool to

rub in the cut, and this must always be avoided. Further, a dull tool is positively detrimental, as work-hardening is bound to result, and when the tool has been re-sharpened it has unnecessary work to do and this may only result in another rapid break-down.

Although it has already been said that a cut once started should be finished straight through, it is preferable not to do so rather than break the rule in regard to the need for sharp tools. It will be found that cast materials will present rather more difficulty than rolled forms, and for this reason the rake angle should be lower, say an average of 10° as compared to 15° for rolled materials.

Hard and fast figures for feeds and speeds are difficult and these must be definitely determined on the job.

Generally speaking, however, the following are fair averages and will at least serve as a guide.

TURNING OF MARTENSITIC STEELS

Rough turning: Deep cuts, with surface speed of about 60 feet per minute and a feed/rev. of $\frac{1}{50}$ inch, top rake of 10°.

Medium finish: Light cuts, with surface speed of about 90 feet per minute and a feed/rev. of $\frac{1}{36}$ inch, top rake of 15°.

Finish turning: Light cuts, with surface speed of about 120 feet per minute and a feed/rev. of $\frac{1}{48}$ inch, top rake of 12°.

These figures apply normally to martensitic steels when their treatment has been such as to bring them within the range of 45/60 tons tensile, but at the higher figures it would be better to reduce the speeds.

If the components are required at a higher tensile strength than 60 tons, it would be preferable to machine annealed materials and then proceed with the heat-treatment, leaving only the final grinding to be completed afterwards.

TURNING OF AUSTENITIC STEELS

Rough turning: About half the depth of cut used for martensitic qualities, with a surface speed of about 50 feet per minute and a feed/rev. of $\frac{1}{48}$ inch, top rake of 12°.

Medium finish: Light cuts with surface speed of about 70 feet per minute and a feed/rev. of $\frac{1}{50}$ inch, top rake of 12°.

Finish turning: Light cuts with surface speed of about 80 feet per minute and a feed/rev. as fine as possible, top rake of 10°.

In austenitic steels the co-efficient of expansion is greater than with ordinary steels and due allowance has to be made for distortion and expansion.

The cooling-fluid should be a soluble oil, and a liberal supply must be constantly flowing on to the point where the cut is taking place.

DRILLING

This is an operation offering a large amount of difficulty and certain fundamental precautions must be observed.

The work must be held rigidly and the centre-pop marks must be as light and small as possible. Large and hard-driven centre-pops are a definite cause of work-hardening,

so that the operation is made unnecessarily difficult from the outset.

The drills must not have any tendency to springiness and for this reason should be as short and stubby as the depths of hole to be drilled will permit. If necessary, cut down the length of the normal drills before using them.

The drills must be sharp; a drill that has lost its keen edge will result in work-hardening and will undoubtedly have to be withdrawn before completion of the hole, thereby wasting time and, furthermore, presenting a work-hardened face for the new drill to overcome.

Make sure, therefore, that the drill is in a condition to complete a hole once started. The austenitic group will be more difficult than the martensitic and have a greater tendency to rapid work-hardening. The speeds will therefore have to be lower.

At no time during the operation should the drill be allowed to rotate idly in the hole being cut. The smaller the hole, the greater is the necessity for observing these rules more rigidly.

By small holes is meant say $\frac{1}{8}$ inch diameter and under, whilst below $\frac{1}{16}$ inch diameter the need for care is disproportionately intensified.

Obviously, the depth of hole in relation to diameter is a further factor to be regarded; the difficulty increasing with greater depths. On these small-size drills it is detrimental to increase the load on them, as they would be likely to be broken in the work; on the other hand, if the feed is too fine the drill is liable to rotate without cutting and so cause work-hardening. The only safe course is to commence with as short a drill as the finished depth of hole will permit.

The designer should help here by endeavouring to avoid holes which are deep in relation to diameter.

This rule should be observed in all drilling-holes if possible, not only with the smallest sizes. Good-quality high-speed twist drills should be used, and it is essential to keep the work as cool as possible, forced coolant being recommended, as heat is more quickly generated in drilling than in most machining operations.

Feeds should be on the light side, whilst for martensitic steels peripheral speeds should be about 75 per cent. of those used for ordinary mild steels and for austenitic steels about 50–60 per cent.

It will be appreciated that a close observance of the foregoing suggestions will tend to cheapen costs both from the operation time of the job and the maintenance cost of drills.

SCREW-CUTTING

The main essential of screw-cutting on stainless steels is to keep the dies sharp.

A type of die which does not clog with swarf is to be preferred.

Whenever possible, only take one run with the die to obtain the finished thread.

For machine threads, the speeds should be similar to those specified for rough turning, but should be followed afterwards by a chaser to clean up the thread.

For ordinary screw-cutting with martensitic steels the speed could be about 10 per cent. lower than those specified for turning, whilst with austenitic qualities, say about 20 per cent. lower.

TAPPING

Special taps (with ground threads) are now on the market for use with stainless steels and these are most strongly advised and even essential, also they must always be kept perfectly sharp. The designer can help here by avoiding blind holes as far as practicable, whilst the drilled hole should always be as large as possible preparatory to tapping.

Stainless steels are very prone to expand in towards the roots of the tap, and whenever convenient, avoid reversing as much as possible in order to minimize work-hardening.

Choose a suitable lubricant; some manufacturers recommend a mixture of tallow, white lead, and boiled linseed oil.

For hand tapping, liberal application of neats-foot oil is very good.

In machine tapping, the speeds should commence at a low rate and gradually be increased so long as torn threads are not caused by undue increase.

SAWING (POWER)

This should not be attempted with anything but high-speed steel blades; carbon blades are quite useless and a waste of time.

Blades with approximately eight teeth to one inch are preferable and a soluble oil should be used as a lubricant.

The outstanding rule to be observed is that rubbing must not be permitted on the return stroke; this causes work-hardening with all its attendant troubles as previously described.

The number of strokes per minute can be taken at 60 to represent a fair average.

PLANING AND SHAPING

The same general rules as for turning are to be observed and keen raked tools must be used. Speeds of, say, 25 feet per minute are suitable for martensitic qualities, but for austenitic qualities reduce this by 25 per cent.

MILLING

The type of the cutter used is the deciding factor as regards the speeds and feeds to be adopted, and these must be determined on site according to the requirements of the work.

Similarly, as explained under the paragraph concerning turning, the rigidity of the machine is a basic factor in successful milling, whilst a keen cutting-edge and good-quality cutters are the other essentials.

Chatter or vibration of any kind which is communicated to the cutter will be detrimental to the success of the operation, as this causes work-hardening, which, in the case of a milling operation, is very difficult to avoid by the very nature of the milling cutter action, since the sliding and crushing action which inevitably precedes the cutting-action of each tooth tends to develop such work-hardening.

If, however, these points are carefully watched, then peripheral speeds of 50 to 60 feet per minute, reckoning on medium cuts, can be accomplished.

SUITABLE TOOLS

Before leaving the machine shop section it would perhaps be helpful to discuss generally the question of tools for use with stainless steels. As already intimated, much of

the machining difficulty encountered in the pioneer days of these steels was due to lack of really effective cutting-tools.

This point has received a large amount of expert attention and there is now no difficulty in obtaining high-grade tools capable of attacking the work with minimum difficulty. Ordinary carbon steels are quite useless and will be expensive both in their maintenance costs and also on the length of time spent on the operation.

Therefore only the very best grades of High-speed Tool Steels should be used.

It is not proposed to tabulate a list of such tools here, as all the leading manufacturers now supply qualities under their own trade names and catalogues or lists can be obtained upon application.

First capital cost of these tools will certainly be higher, but not disproportionately so, and over a period the maintenance costs will most certainly show a saving.

For lathe tools it is quite satisfactory to adopt the 'tipped' tools which are now on the market.

This means that a suitable section of high-speed tool steel is mounted on the ordinary steel shank in order to provide the necessary specially keen cutting-edge. Incidentally, such tools can be re-tipped, an allowance being made on the old shanks. The necessity for these special tools is not only applicable to machining operations, but should be observed in all other processes, including drilling, reamering, hack-sawing (both hand and power), tapping, screwing, filing, shearing, and punching.

VIII

MANIPULATION

SOLDERING

Both soft and hard soldering of stainless steels is possible.

For soft soldering the parts to be soldered should be very thoroughly cleaned and a good flux to use is zinc chloride dissolved into a 50 per cent. solution of hydrochloric acid, used with ordinary tinsmith's solder which is quite satisfactory. The flux and acid remaining on the work after soldering should be removed thoroughly.

In hard soldering the special silver solders are used, with borax as a flux. The parts to be soldered should first be cleaned with 50 per cent. H.Cl. and rinsed with clean water.

To assist in maintaining the best corrosion-resisting properties of stainless steels when hard soldering, it is advisable not to use solder with a high silver content.

This is beneficial on the score of both cost and a higher melting point.

The latter is important, as with a high silver content the solder melts at about 775° C., whilst with a high copper content it will not fuse until reaching about 880° C.

Temperatures below this latter figure are very injurious to stainless steels and the ideal soldering temperature would be as high as 950° C.

The addition of about 3 per cent. nickel content to the solder would be very advantageous from the increased adhesive qualities, higher mechanical strength, and greater corrosion-resisting properties. Summarized,

then, the author would suggest the following analysis for hard solder for use on stainless steels:

Copper	50–55 per cent.
Zinc	27 ,, ,,
Silver	15–20 ,, ,,
Nickel	3 ,, ,,

This should vary slightly according to the grade of stainless steel being worked and test joints should be made with several varying compositions.

Tin, lead, iron, and cadmium additions should be avoided. Special attention will be necessary to ensure thorough protection of the surface by the flux, as the high temperatures will tend to cause the deposition of a refractory black oxide, which means that the adherence of the solder is prevented.

The blowpipe method is, of course, used in hard soldering.

If the work to be done is of sufficient thickness as to warrant welding (assuming a welding quality of stainless steel), then this is preferable to hard soldering, as the soldering mixture is not likely to be so good from the corrosion-resisting point of view as the filler-rod in welded work.

BRAZING

Brazing can be undertaken by one of two methods, namely the 'blowpipe' and the 'hot-dipping' respectively.

Brazing is rather more difficult than soldering when using stainless steels.

Dealing first with the blowpipe method, it is an essential that the surfaces to be brazed are afforded adequate protection during the heating. Such heating must be

administered slowly, as the flux must not on any account be permitted to boil. If this should occur it will be found that the flux leaves the surface, and an oxide will form on the surface of the work. The flux used is borax (ground borax glass is best in this case) and it is not possible for it to dissolve the oxide, obviously, therefore, the flux must be used in such a way as to prevent any oxidation.

The temperature will need to be rather higher than that used on ordinary mild steel.

In the hot-dipping process, cleaning should be executed first in the normal manner and the temperature of the parts to be brazed must then be brought to a temperature closely approximating that of the molten metal in the dipping-bath. If a scum should form on the surface of the flux, which then adheres to the surface of the dipped parts, it will probably mean that the brass will not cover the work evenly.

If this does occur, then apply a little of the soft-soldering method flux on the parts to be brazed as a preliminary to hot-dipping.

After both hard soldering and brazing the surplus flux can be removed easily by plunging the work in a 5 per cent. solution of boiling caustic.

WELDING OF STAINLESS STEELS

The ordinary straight chromium steels were found to be very difficult to weld, in fact, after welding had been carried out, a certain area some distance from the weld was no longer stainless steel in the literal sense.

In welding, the process demands a temperature of about 1,200° C. and an area some distance from the weld is held

at a temperature of about 900° C., this temperature is within the critical range (550–900° C.).

This causes a precipitation of what is known as the carbides. These carbides are rich in the chromium content of the steel, perhaps containing as much as 90 per cent. chromium, taken entirely from the zone of metal held at the critical temperature. This impoverishment of the affected area is such as to render the metal subject to subsequent corrosion attack.

This would be partially remedied by normalizing the entire piece of work upon completion by heating up to 1,150° C. and cooling, but this means an extra process with the attendant increased production cost.

In order to prevent this, 1 per cent. of titanium was added and found to be fairly satisfactory, but the corrosion-resisting qualities were still somewhat impaired.

Some manufacturers discovered that molybdenum was an improvement upon titanium as it had good acid-resisting qualities and thereby did much to prevent 'weld-decay', as it is called. This term is not literally true, as the metal subject to attack is actually a belt in the parent metal. Actual weld-decay would be an unsound weld which was thereby rendered liable to attack.

As in ordinary steels, the welding can be carried out either by the oxy-acetylene or electric process.

It is advisable to use descaled sheets for welding, as absolute cleanliness is a first essential. If descaled plates are not used, then the cleaning must be very thoroughly conducted, using a wire brush vigorously and then washing with a descaling mixture.

If dirt is left against the welded parts, this is likely

to act as a weak spot for the attack of corrosion. Where the job is to be welded on both sides, the opposite side must be recleaned after the welding of the first side.

Dealing first with the oxy-acetylene process, the first rule is that the flame must be neutral. With excess acetylene a reducing flame will be obtained, resulting in a brittle weld which will be very liable to corrosive action. On the other hand, an excess of oxygen will give an oxidizing flame which causes blow-holes and the presence of oxides, the result being an unsound weld. Actually speaking, no blue flame should be seen, but a small blue tip to the white cone is permissible, thus indicating the absence of an oxidizing flame, and it is certain to be nearly neutral. The welder will find that constant adjustment of the flame is necessary. This is apparently due to the increasing heat of the blowpipe tending to cause an oxidizing flame.

Too high a pressure should be obviated on thin sheet work.

There is now on the market oxy-acetylene equipment which claims to obviate the need of the welder's skill in maintaining a neutral flame.

As already explained, the flame gets out of adjustment during the course of the work, owing to the counter-pressures created by the parts to be welded and by the heating of the gaseous mixture in the head of the blowpipe. This effect is noticed particularly when gas is at the lowest pressure and consequently the proportion of the gas in the mixture is reduced.

The equipment referred to is the 'Frama' process, and this automatically ensures the equality of the pressures of the two gases on the arrival at the blowpipe.

In the first place the excess of oxygen is eliminated, and in view of the fact that no heat units are wasted to heat the excessive oxygen, the temperature of the flame is higher; therefore, with balanced consumption of the two gases the flame is strictly neutral and thereby helps in the execution of sound welds.

These uniform pressures are obtained by the membrane of the acetylene regulator being operated by the pressure of the oxygen previously expanded, instead of by a spring as in the hand-controlled units. By this arrangement the acetylene leaves the regulator at a pressure equal to that of the oxygen irrespective of the size of the flame. The right mixing ratio is obtained by a dosing cock of special design placed at the entrance of the gases to the blowpipe; it contains a double-passage dome, the apertures of which are arranged in such a manner that, with any position of the cock, the free passage sections are in proportion to the respective densities of the oxygen and the acetylene. The oxygen expansion valve is of the two-stage type instead of the usual single-stage. The suppliers of this equipment are Messrs. C. H. Johnson & Sons, Ltd., Smedley Road, Manchester, 8.

In sheet welding a rod is to be preferred to strip, and such rod should preferably be heavier than the gauge of the sheet and should be of equivalent quality to the parent metal.

Rod $\frac{1}{16}$ inch diameter of A. 2 quality costs about 3*s*. per lb. fully softened and descaled.

Another important factor is the greater expansion of stainless steels as compared with ordinary mild steels. This is probably 50 per cent. higher and due allowance will

need to be made. To assist in overcoming contraction stresses the plate edges should be spaced at least $\frac{1}{16}$ inch apart.

For a long seam the space should diverge from the commencing point in order that it will draw together during the progression of the weld. For this reason 'tacking' should never be resorted to by the welder.

The generated heat of the work will not be conducted away so rapidly as in the case of mild steels, which will cause an undesirable curtailment of the hot zone. This may be partially counteracted by playing the blowpipe over a slightly wider area than is the usual practice.

Generally speaking, the use of flux is unnecessary in the welding of stainless steels, but it may be used on some qualities with a certain amount of advantage, but this must be left to the discretion and experience of the welder. If a flux is used, however, it is imperative that the work is cleaned afterwards in the manner described under the paragraph concerning brazing. With electric welding, the cleanliness of the work to be welded is just as important as in oxy-acetylene welding. The arc should be as short as possible: if too long it will be found that proper fusion is not obtained and there will also be insufficient penetration, whilst the deposit would probably be unsound.

The electrode should be of the same type of material as that being welded. The thinner gauges of sheets, say below 14 gauge, should not be welded electrically for the best results, oxy-acetylene being preferable on these thin gauges. The electrodes should be used at the lowest possible current strength, certainly less than with mild steel.

In order to keep distortion to a minimum, the deposits

should be kept as short as practicable. As already intimated the use of the special welding quality stainless steel is advocated, as heat-treatment is then unnecessary.

Except in the case of thin sheet work, it is preferable to deal with stainless steels by the electric process, as the slowness and greater danger of undesirable overheating in the oxy-acetylene process is much more liable to disturb the parent metals.

In regard to welding-times for stainless steels it would be reasonable to say that with the oxy-acetylene method the increase over average times for mild steel would be in the neighbourhood of 25 per cent. The major portion of this increase is due to the loss of time in the very essential careful preparation and the constant need for flame attention.

In the electric process, the increase would only be slight, say about 10 per cent.

Welding-times in mild steel are given in *The Practice of Engineering Estimating*.

HEAT TREATING AND DESCALING

Where it is desirable or necessary to work with stainless steels in a softened condition, such as in cold pressing, spinning, or hammering, this can be achieved by heating up to not less than 1,000° C. for a short time, followed by quick cooling; very thin sections in air, thicker sections in water.

Oxidation will be a natural result of this heat-treatment, although not to quite the same extent as mild steel under similar conditions, and the scale will need to be removed.

The method of descaling is as follows:

Immerse the part in a bath containing a solution of equal volumes of commercial hydrochloric acid to which is added 5 per cent. of the total volume of commercial nitric acid and about 1 per cent. of the total volume of a pickle retainer.

There is a variety of pickle retainers to choose from including Galvene, Rodine, Pickelette, and Ferro Cleanol.

The bath should be used at a temperature between 50° and 60° C., this being attained before immersing any parts.

The bath will require renewing at intervals, the general opinion being that not more than 20 per cent. of ferric chloride is permissible.

After this pickling process, a thorough washing in running clean water is essential in order to remove all traces of harmful acid.

The action of the pickling bath is the softening of the scale. Should this not wipe off easily upon removal of the part from the bath, a further short immersion should be given.

POLISHING

The polishing of stainless steels is carried out by a succession of graded emery applications. The coarseness of the first grade is entirely dependent upon the condition of the surface to be polished. As a good average, No. 80 emery is likely to be most suitable, but the important point is to remove the initial surface of the article and get rid of all irregularities. In the case of very bad surfaces, it would be as well to use a fine grind.

The emery can be mounted on the ordinary leather-faced buff.

The No. 80 can be followed by No. 120, then continuing with flour emery mounted on a felt block. For a final mirror-finish chromic oxide is used. This is used with a binder of mutton fat (stearine), being smeared on to the felt blocks or disks.

ETCHING

The etching of ordinary mild steels is a very simple matter, but with stainless steels it will be found much more difficult.

The reagent recommended as being most suitable consists of four parts of water, four parts of concentrated hydrochloric acid, and three parts of concentrated nitric acid.

This should be used at room temperature and with the utmost care. This latter point is stressed owing to the highly corrosive nature of such a solution.

For the same reason the depth of etch can be controlled according to the length of time permitted for the action to take place.

IX

TANKWORK

THE construction of tanks and vessels in stainless steels is worthy of careful survey.

For tanks not involving pressure, in order to conserve unnecessarily high costs, it may be found permissible to form an inner lining with light-gauge sheets inside an ordinary mild-steel tank.

Alternatively, a light-gauge stainless steel tank can be made and placed inside a supporting cradle of mild-steel sections.

If a number of fittings are to be positioned on the tank, then this latter course would be preferable, as the joints through an outer lining are often difficult and troublesome.

In dye barks and similar plant, a stainless-steel lining may be formed inside a timber container. The joints are formed on the external side of the lining, i.e. next to the timberwork. These need not be riveted or welded, but a double dove-tail, as shown in Fig. 1 makes a very satisfactory joint. The seam can be kept quite small in width, and, being on the underside of the polished lining, the timber can be grooved to take these and thus preserve an even internal finish. Before placing the lining inside the timber container, the edge of the joint on the external side is seamed with solder, or, in the case of heavier gauges, could be welded. This is clearly indicated in Fig. 1. If using stainless-steel sheets with one highly polished surface, by obviating riveting or welding, an unbroken finished surface is presented to the contents of the tank,

thereby preventing possible damage to the material being handled.

In pressure vessels, the requisite thickness of platework will need to be calculated and stainless-steel sheets of such thickness employed.

All pads should be of the same quality steel as the main vessel in order to ensure soundness and safety if of welded fabrication.

FIG. 1. Method of joint for inner linings.

In flanged joints, advantage can often be taken of ordinary quality mild-steel backing rings.

In vessels of riveted construction, rivets of similar specification to the platework should be used.

Small sizes of rivets can be riveted cold, but the portion for heading over should be as short as possible compatible with sound riveting, as an excess of blows will create work-hardening and add to the difficulty of procuring well-riveted joints, and also tend to destroy partially the corrosion-resisting properties of the rivets.

On the larger sizes of rivets, hot riveting will necessarily be entailed, and with most qualities of stainless steel the commencing working temperature should not be less than 1,100° C., and they should be driven quickly before the temperature drops below 950° C. At temperatures less than this the rivet will work-harden. It is not necessary to hammer rivets until cold to get a tight rivet, as owing to the higher co-efficient of expansion of stainless-steel

rivets they will shrink, causing pressure at the rivet heads.

Whilst riveted construction will follow identical lines as for mild-steel platework, in welded fabrication the disposition of the weld need not slavishly follow riveted practice. In the latter, owing to practical considerations, the disposition of the joint is often not placed at the most advantageous position. The weld should be positioned in such a manner that the working stresses are uniform throughout the entire weld.

Butt welds are always advisable, particularly in cylindrical vessels. There is no need for lap-joints, which obviously destroy true circularity, whilst the joint is loaded eccentrically with the internal pressures.

Furthermore, with a lap-joint it is more difficult to obtain proper penetration at the junction of the plates and with alternating stresses the weld may develop a fracture.

Similarly, joints should be avoided at corners as far as practicable. Failing this, then suitably radiused welds must be made in order to minimize the concentration of undue stress. Where a change of section occurs, a weld should be avoided entirely if possible, or at least arranged with sweeping lines in order to obtain only an average stress.

Smooth welds are highly desirable; rough welds invariably have their weak spots, and internal welds should be ground.

Whilst on this subject of welds, the reader is reminded that it is nearly as important for the weld not to exceed the strength of the parent metal as it is for it not to be less than the strength of the parent metal. A weld having a higher

ultimate strength than the parent metal will cause unbalanced stresses by virtue of its ability to resist deformation, and a weld having higher ductility will cause local

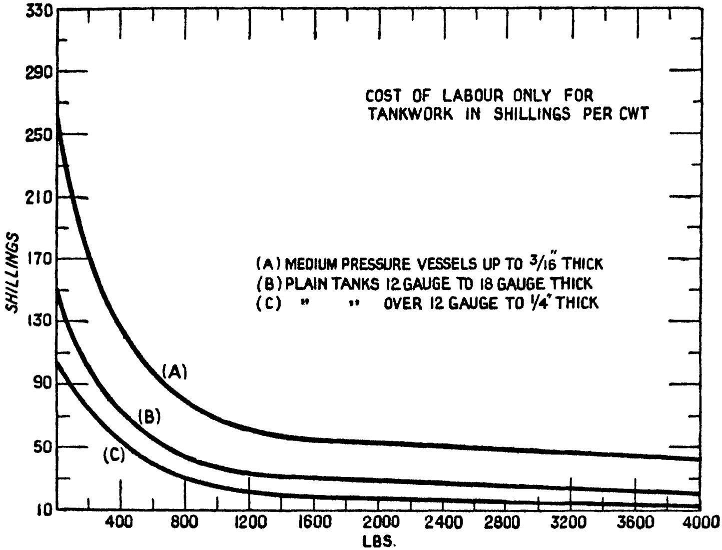

FIG. 2. Graph showing labour costs of tankwork.

deformation, and the tank may have to be 'rounded-up' after completion, which is very undesirable.

Obviously, it will not be possible to obtain a weld having absolutely identical characteristics with the parent metal, but this should not vary more than, say, 15 per cent. either way.

The question of welded fabrication has been discussed at greater length than riveted construction owing to the fact that, comparably, it is much newer to the field of engineering, and as yet has not been employed to anything

approaching the same extent, but it is rapidly gaining ground.

In regard to the cost of tankwork in stainless steels, it is difficult to fix overall rates on a size or weight basis

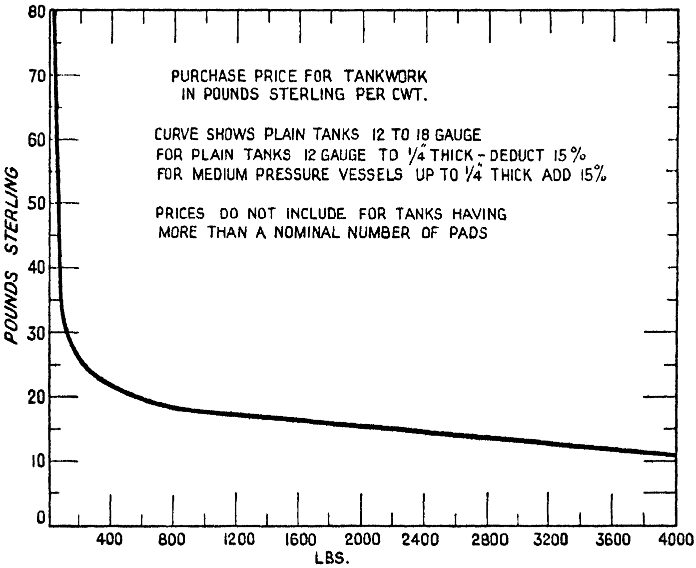

Fig. 3. Graph showing purchase costs of tankwork.

owing to the large variety of classifications which would need to be detailed. It would, perhaps, be preferable to take out material costs from the several tables of sheets, &c., and to arrive at labour costs only on a weight basis.

For this purpose graphs (see Fig. no. 2) are given to show average labour costs on plain tankwork in varying gauges and also on tankwork involving a greater amount of labour due to flanging, fixing of pads, and the like.

To these labour figures must be added shop expenses, administration charges, profit, &c.

For the purpose of the engineer who is only concerned with the 'bought out' costs of such tanks, graphs are again given (see Fig. no. 3) for the several classifications, to indicate the average prices which might be expected.

X

PIPING INSTALLATIONS

In those cases where equipment of stainless-steel construction has to be installed, such as in chemical and allied trades plant, the question of interconnecting piping and fittings plays an important part.

The inclusion of such pipe-lines in stainless steels is a very costly matter, and therefore needs lengthy consideration.

Where pressures are involved, the heavier gauges necessitated will add seriously to the cost and with due thought it might be found possible to use a slightly thinner gauge than is usual with ordinary wrought-iron tubing, due to the greater strength of the stainless steels. If the conditions are not too severe, it will probably be quite in order to use butt-welded tubing, which will show a reduction on the prices of solid-drawn tubing. Comparative prices are indicated in the price-list graphs included in this chapter.

Where allowances have not to be made for pressures, then light gauges can be used; with these it is possible to lip back the tubing on to ordinary mild-steel backing rings.

This shows a great saving in cost, not only in materials, but also in the labour saved by virtue of the screwing operation being eliminated. The screwing of stainless-steel tubing is a matter of some difficulty, and as already specified in the machine-shop section, when referring to screwing, special quality dies are the first essential. This is equally true for both hand and machine screwing. It

will be apparent, then, that the labour costs of piping installations in stainless steels are definitely higher.

Rather more care should be exercised in laying out pipelines in stainless steel than in ordinary wrought-iron tubing. A glance at the prices per foot will serve to show the prime importance of keeping total runs down to the very minimum, also, wherever possible, correct lengths should be specified ready for erection on site in order that cutting to waste is obviated. The number of special fittings should also be avoided as far as practicable in an endeavour to conserve on the already high cost. Where facilities permit, welding up of special connexions on site should result in economies, but a thorough understanding of the welding difficulties explained in the chapter devoted to that subject will be necessary. The cost of fittings cannot well be indicated in graph form, but a price-list is included which will serve as a basis for all normal work.

For valves, cocks, strainers, &c., in stainless-steel construction, special quotations from the manufacturers is advocated whenever time permits.

If this course is not convenient, it will be found that in a reasonable specification, a good approximation can be arrived at by taking four times the cost of similar fittings in their normal construction.

To assist in arriving at more reliable figures, a few lists of typical fittings are quoted in this text, and with these as a guide, it should be possible to interpolate others from price-lists of standard construction without undue danger. In regard to prices per foot of stainless-steel tubing, it will not be possible to quote herein the prices of various bores in all gauges in list form, but the graphs contained in the

following pages will indicate average present-day costs. This method will be more comprehensive than tabulating typical sizes. See Figs. nos. 4, 5, 6, and 7.

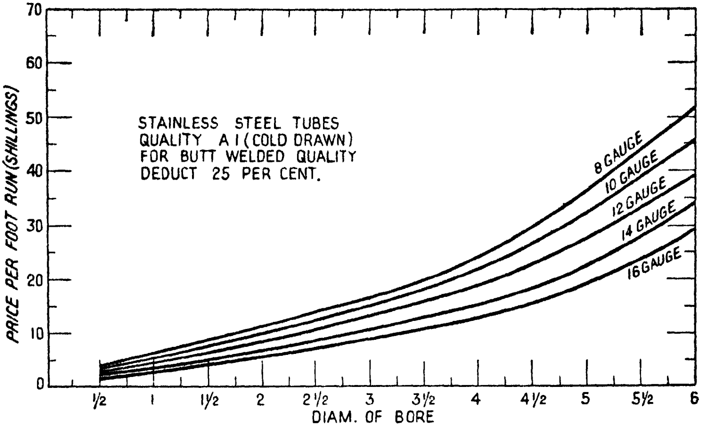

FIG. 4. Graph showing price per foot of tubing, in A. 1 quality.

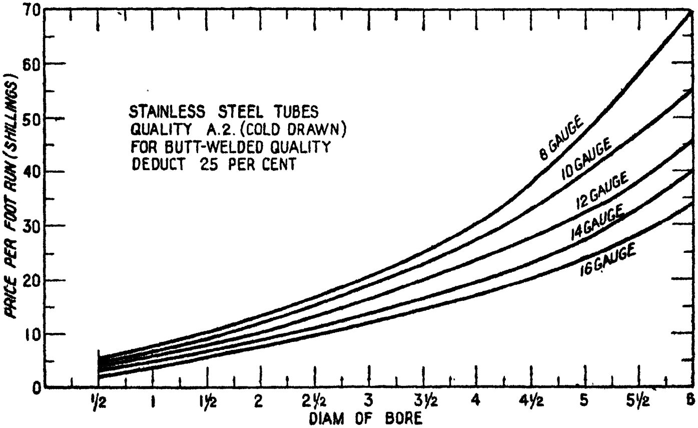

FIG. 5. Graph showing price per foot of tubing, in A. 2 quality.

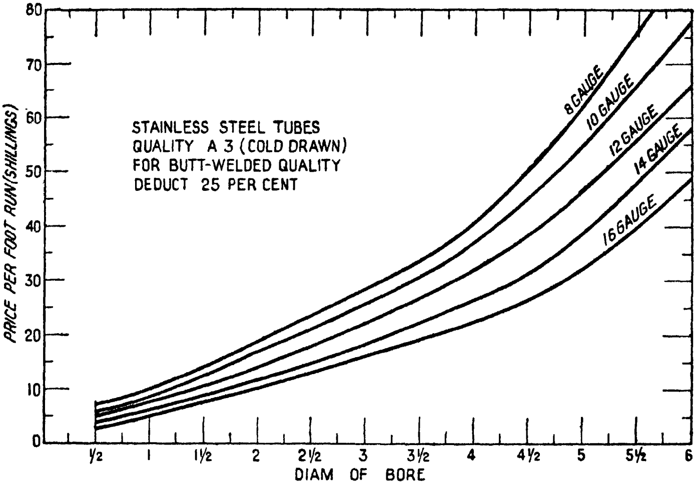

FIG. 6. Graph showing price per foot of tubing, in A. 3 quality.

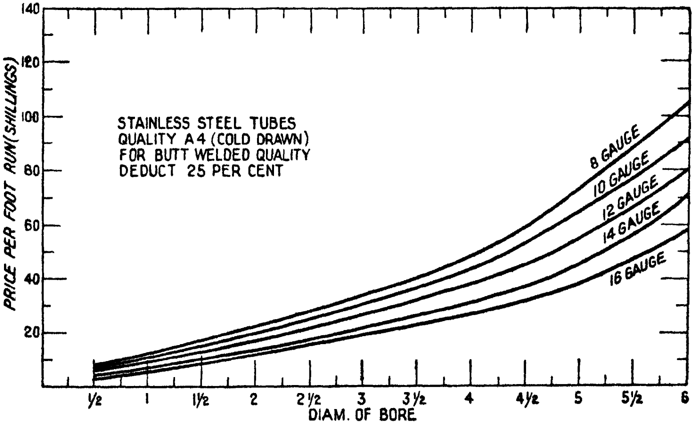

FIG. 7. Graph showing price per foot of tubing, in A. 4 quality.

In regard to erection on site, figures are given in *The Practice of Engineering Estimating*, for erection costs of pipe lines in cast iron, wrought iron, copper, and aluminium.

For stainless steels it is rather more difficult to assess a definite percentage of the purchase cost as being reasonably indicative of the probable erection cost.

Based on this method, however, it is suggested that 10 per cent. of the purchase cost, after deducting the amounts included for such items as valves and cocks, should suffice for overall costs.

The reader is reminded, that, although the cost of valves, cocks, traps, &c., is to be deducted before applying the percentage, it must be appreciated that in a piping arrangement involving an abnormal amount of such fittings, due allowance must be made for erection of same over and above the figure arrived at from the percentage basis.

STAINLESS-STEEL TUBE FITTINGS

Quality A. 1

Bore—Inches	¼	⅜	½	¾	1	1½	2 *14 gauge*	3 *12 gauge*	4 *10 gauge*	5 *10 gauge*	6 *8 gauge*
	s. d.	*s. d.*	*s. d.*	*s. d.*	*s. d.*	*s. d.*	*s. d.*	*s. d.*	*s. d.*	*s. d.*	*s. d.*
Bends (flanged) .	..	..	..	..	..	26 0	42 6	58 6	87 0	112 6	175 0
Elbows (screwed)	1 9	2 0	2 9	3 6	4 6						
Tees (screwed) .	2 3	2 9	4 6	5 3	6 0	13 0	16 6				
Tees (flanged) .	..	..	..	..	..	..	55 0	78 0	112 6	145 0	220 0
Reducing tees (flanged) .	..	..	..	..	..	..	50 0	76 0	110 0	140 0	210 0
Sockets . .	1 5	1 8	2 10	3 7	4 0						
Nipples . .	1 0	1 2	1 11	2 8	3 1						
Unions . .	5 6	6 6	12 6	17 6	24 0	40 0	50 0	100 0	150 0	240 0	400 0

STAINLESS-STEEL TUBE FITTINGS

Quality A. 2

Bore—Inches	$\frac{1}{4}$	$\frac{3}{8}$	$\frac{1}{2}$	$\frac{3}{4}$	1	$1\frac{1}{2}$	2 *14 gauge*	3 *12 gauge*	4 *10 gauge*	5 *10 gauge*	6 *8 gauge*
	s. d.	*s. d.*	*s. d.*	*s. d.*	*s. d.*	*s. d.*	*s .d.*	*s. d.*	*s. d.*	*s. d.*	*s. d.*
Bends (flanged) .	..	..	..	..	..	30 0	47 6	67 6	100 0	130 0	200 0
Elbows (screwed)	2 0	2 3	3 3	4 0	5 0						
Tees (screwed) .	2 6	3 0	5 3	6 0	7 0	15 0	19 0				
Tees (flanged) .	..	..	..	..	..	..	62 6	90 6	130 0	167 6	250 0
Reducing tees (flanged) .	..	..	..	..	..	..	57 6	87 6	125 0	160 0	240 0
Sockets . .	1 6	1 9	3 0	3 9	4 3						
Nipples . .	1 0	1 3	2 0	2 9	3 3						
Unions . .	5 6	6 6	12 6	17 6	24 0	40 0	50 0	100 0	150 0	240 0	400 0

STAINLESS-STEEL TUBE FITTINGS

Quality A. 3

Bore—Inches	¼	⅜	½	¾	1	1½	2 *14 gauge*	3 *12 gauge*	4 *10 gauge*	5 *10 gauge*	6 *8 gauge*
	s. d.	*s. d.*	*s. d.*	*s. d.*	*s. d.*	*s. d.*	*s. d.*	*s. d.*	*s. d.*	*s. d.*	*s. d.*
Bends (flanged) .	..	..	..	..	..	36 0	57 6	82 6	120 0	157 6	240 0
Elbows (screwed)	2 6	2 9	4 0	5 0	6 0						
Tees (screwed) .	3 0	3 9	6 6	7 3	8 6	18 0	23 0				
Tees (flanged) .	..	..	..	..	..	..	75 0	110 0	157 6	200 0	300 0
Reducing tees (flanged) .	..	..	..	..	..	..	70 0	105 0	150 0	190 0	290 0
Sockets . .	1 9	2 0	3 6	4 6	5 0						
Nipples . .	1 2	1 6	2 5	3 3	4 0						
Unions . .	5 6	6 6	12 6	17 6	24 0	40 0	50 0	100 0	150 0	240 0	400 0

STAINLESS-STEEL TUBE FITTINGS

Quality A. 4

Bore—Inches	¼	⅜	½	¾	1	1½	2 *14 gauge*	3 *12 gauge*	4 *10 gauge*	5 *10 gauge*	6 *8 gauge*
	s. d.	*s. d.*	*s. d.*	*s. d.*	*s. d.*	*s. d.*	*s. d.*	*s. d.*	*s. d.*	*s. d.*	*s. d.*
Bends (flanged) .	..	..	..	..	..	42 0	66 0	92 6	137 6	180 0	280 0
Elbows (screwed)	2 9	3 0	4 6	5 6	7 0						
Tees (screwed) .	3 6	4 0	7 3	8 3	9 9	20 0	25 0				
Tees (flanged) .	..	..	..	..	..	..	85 0	125 0	175 0	230 0	340 0
Reducing tees (flanged) .	..	..	..	..	..	..	80 0	120 0	170 0	220 0	330 0
Sockets . .	1 10	2 2	3 9	4 8	5 3						
Nipples . .	1 3	1 7	2 6	3 6	4 2						
Unions . .	5 6	6 6	12 6	17 6	24 0	40 0	50 0	100 0	150 0	240 0	400 0

GLAND COCKS—STRAIGHT-THROUGH PATTERN

Tested to 150 lb. per square inch

All Qualities, with Ni-Resist Plugs

Bore. Inches	*Flanged type*			*Screwed type*		
	£	*s.*	*d.*	£	*s.*	*d.*
¼	1	5	0		15	0
⅜	1	12	0		19	6
½	1	12	0	1	6	0
¾	2	0	0	1	12	0
1	2	5	0	1	17	0
1½	5	0	0	3	14	0
2	6	14	0	4	17	6
3	10	0	0	7	10	0
4	18	10	0	13	10	0
5	22	10	0			
6	30	0	0			

NOTE: Plugs of Ni-resist cast iron (see p. 83) are included in the above cocks.

STAINLESS-STEEL VALVES (FLANGED)

Tested to 150 lb. per square inch

All Qualities

Bore. Inches	*Fullway pattern*			*Parallel slide and screw-down stop*			*Swing-gate check*		
	£	*s.*	*d.*	£	*s.*	*d.*	£	*s.*	*d.*
1	5	5	0	5	10	0	4	10	0
1½	6	10	0	7	0	0	5	10	0
2	7	10	0	8	0	0	7	10	0
2½	12	10	0	13	0	0	10	10	0
3	16	0	0	17	0	0	14	0	0
4	24	0	0	25	0	0	20	0	0
5	31	0	0	33	0	0			
6	40	0	0	42	0	0			
7	50	0	0	53	0	0			
8	62	10	0	66	0	0			
9	78	0	0	82	0	0			
10	95	0	0	100	0	0			

The above valve prices are intended as a guide only. Owing to the great variety and numerous specifications for valves, it is not possible to quote more than typical examples. Furthermore, it must be understood that prices will vary from different manufacturers. Where possible, enquiries should be sent to the makers.

STAINLESS-STEEL WATER-GAUGE FITTINGS

Water-gauge fittings, in all qualities, three cock type, asbestos packed, screwed female gas thread:

Bore of Connexions	*Price* £	*s.*	*d.*
½ inch	5	10	0
⅝ inch	7	0	0
¾ inch	8	0	0

Above prices are for fittings unpolished. If desired in polished condition, add 15 per cent.

XI

SPECIFICATIONS MET BY THE SEVERAL GRADES OF STAINLESS STEELS

Type	*Specification*
M. 1	B.S.I. S. 62 D.T.D. 199
M. 2	B.S.I. S. 80 D.T.D. 60A D.T.D. 146A D.T.D. 163 D.T.D. 168 D.T.D. 185A D.T.D. 211 D.T.D. 225
A. 1	D.T.D. 181A
A. 2	D.T.D. 166A D.T.D. 171A D.T.D. 176A D.T.D. 181A D.T.D. 189 D.T.D. 207 D.T D. 211
A. 3	Special
A. 4	Special

XII

MAIN USES FOR THE SEVERAL GRADES OF STAINLESS STEELS

Type	*Uses*
M. 1	Cutlery, machine parts with high stresses, furnace parts, turbine blades, exhaust valves of I.C. engines.
M. 2	Pump spindles where handling brine and acid waters, steam and water valve parts, sea-planes, highly stressed machine components.
A. 1	Chemical plant, dye barks, food equipment, domestic articles, decorative trades, architecture.
A. 2	Dye barks, dairy plant, laundry machinery, welded fabrications, automobile and aero. parts, chemical plant and allied trades.
A. 3	Chemical plant, welded fabrications, dyeing, plant handling sulphuric acid, paper manufacture.
A. 4	Ditto.

XIII

OTHER CORROSION-RESISTING ALLOYS

PERHAPS this work, although primarily intended as a study on stainless steels, would not be quite complete without at least a short reference to several other corrosion-resisting alloys which are now finding their place in engineering.

INCONEL

One such alloy is known as 'Inconel' and is possessed not only of corrosion-resisting properties, but also heat-resisting qualities combined with high mechanical properties, but which, nevertheless, is quite suitable for fabrication.

At the present time its price is somewhat prohibitive, but where this is not the first consideration, then it may be possible to take advantage of its excellent properties. It has been used with great success in the manufacture of plant for food preparation and handling, enabling various commodities to be handled without any of the ensuing corrosion which takes place, even within plant built of normally good corrosion-resisting materials. Some of the food-handling equipment in which Inconel has been used with beneficial results includes milk products, vinegar, sauces, pasteurizing plant, and the like.

As already intimated, in addition to these excellent corrosion-resisting properties, it will be found that it is impervious to scaling even at temperatures of more than 900° C., which means that it will find useful service in furnace work.

The main content is nickel, the approximate analysis being as follows:

Iron	6 per cent.
Nickel	80 ,, ,,
Chromium	14 ,, ,,

With proper annealing, very low yield points (approximately 14 tons per square inch) are obtained with tensile strengths of 35–40 tons per square inch, whilst with cold-worked conditions such as in cold drawn sections, the tensile strength would be increased to 45–50 tons per square inch, but of course, in this case, the yield point would be higher, say about 35–40 tons per square inch. Its coefficient of expansion is very low, which means very little change of shape and the elimination of undue strains with varying temperatures. It is thereby particularly useful for welded fabrications.

The low yield point upon annealing makes it very suitable material for pressing and bending operations, and elongations of approximately 50 per cent. can be obtained on annealed sheets.

Like stainless steels it has the disadvantage of being susceptible to work-hardening, but certainly not to the same extent nor yet so quickly, which means that quite a reasonable amount of cold hammering could be accomplished. It is amenable to the various forms of working such as soldering and welding and will not present quite such a difficult set of conditions as those encountered in stainless steels.

Taking these various forms of working in the same order as already set out for stainless steels earlier in the text, a brief note is offered under each heading.

CASTING

An electric furnace is used for melting the metal. The 'melt' is made up of electrolytic nickel and low carbon ferro-chromium, the carbon content not to exceed 0·5 per cent. and preferably only 0·25 per cent. Magnesium is used as a deoxidizer.

Dry moulds of open sand are preferable, with reasonably soft cores and a core compound producing the minimum amount of gas.

Large headers are essential as shrinkage is high. Owing to this latter fact, ample provision must be made for such shrinkage.

The lowest temperature compatible with easy running should be observed, whilst the rate of pouring should be fast.

FORGING OF INCONEL

Whilst forgings in Inconel can be accomplished readily either by hand or in dies, a rather different set of conditions is presented comparably with the forging of carbon steel or chromium steels.

Correct heating is an essential to successful forging and, with proper observance, the losses in quality will not be correspondingly higher than for similar forging work in steel.

Inconel is very susceptible to attack by sulphur during heating, therefore the work must not be allowed to be in direct contact with a sulphur-laden atmosphere.

If the sulphur attack is at all severe the loss in mechanical strength is such as to render the finished work very faulty.

Obviously, the main source of sulphur attack is from the

fuel used, and it can be laid down as a hard and fast rule that coal and coke are definitely not satisfactory.

Gas heating is the most preferable method, either Town gas or Natural gas being equally successful. If, for any reason, the use of gas is precluded, oil fuel will probably be available and is satisfactory, but a very low sulphur content should be specified to the suppliers of the oil.

Admittedly, first costs would appear to be higher if forging is carried out with gas or oil instead of with coke or coal, but the high proportions of good work will soon prove to have effected a saving on overall costs of work output.

The heat control with gas or oil burners is much more flexible and is therefore another excellent point in their favour.

In regard to heating temperatures, the best forging range is between 1,000° C. and 1,250° C., the heat colours being bright cherry-red at 1,000° C., altering to orange-red and finally, orange-yellow up to the higher figures respectively.

During heating the furnace should be kept at a temperature 10° C. higher than that at which the work is to be 'pulled'.

The furnace should not be run at an excessively high temperature in an attempt to speed up production by reducing the heating time, as this will prove to damage Inconel. Furthermore, the work should not be left in the furnace after it has reached the desired uniform forging temperature. This means that where several pieces are to be handled together in the furnace, they should be placed in on a time cycle which will ensure the minimum 'soaking' time for each subsequent piece.

The next important point to be watched carefully is that of the furnace atmosphere.

This should be kept in a slightly reducing condition the whole time, the resulting carbon monoxide is not injurious to the metal, as Inconel is not subject to carburization.

In spite of this fact, however, there is no need to have the atmosphere much above neutral condition, as otherwise, difficulty in maintaining the requisite temperature will be entailed.

In drop forging it would be preferable to use alloy steel dies in preference to carbon steel dies.

MACHINING

No undue difficulties will be encountered in the machining of Inconel, although with the normal composition it will be found that considerable heat is generated. Close attention to the lubricant medium is therefore essential; the recommended lubricant being a sulphur-base oil. As with stainless steels, high-speed tools must be used and these must definitely be kept keen.

If fairly low speeds are employed, it will be found to machine uniformly and will not drag.

SOFT SOLDERING

For soft soldering, the parts to be soldered should be perfectly clean and the flux recommended by the makers is Baker's fluid.

This is used with ordinary tinsmith's solder. The flux remaining on the work after soldering should be removed thoroughly.

HARD SOLDERING

In hard soldering, the special silver solders are used together with a flux similar to that described in the notes concerning the welding of Inconel. The same general rules should be followed as already described on p. 36.

It has been pointed out, however, that the use of low silver content solders is preferable in stainless steels. In the case of Inconel, however, this is not the case, and the higher silver content solders must be used.

Joints are usually designed so that the slightly lower physical properties of the filling metals do not produce low structural strength. For instance, a sleeve joint is recommended in tubing with sufficient lap to give adequate strength to the soldered joint.

BRAZING

This will follow on similar lines to the methods described on p. 37.

The brazing compounds should have a relatively high melting-point.

OXY-ACETYLENE WELDING

Inconel has been found to be reasonably easy to weld, certainly no more difficult than the welding of pure nickel.

As with every other metal, cleanliness is of paramount importance, dirt left inside a weld will inevitably be a point of attack for chemical action.

Unlike stainless steel, where the flame must be strictly neutral, it will be found necessary to have a flame with an excess of acetylene.

When the flame is correctly set, a lighter blue flame

(about $\frac{1}{4}$ inch long) should be seen protruding beyond the inner blue flame which burns up against the top of the blowpipe.

This will need periodic adjustment during the course of the work, because as previously explained, the increasing heat of the blowpipe tends to cause an oxidizing flame.

In sheet welding a rod is to be preferred to strip, and a rod of slightly heavier gauge than the gauge of the sheet is advocated for thin gauges; for sheets heavier than 18 gauge, up to 10 gauge, use filler rod of the same diameter as the gauge of the sheet; above 10 gauge use a rod slightly less in diameter than the gauge of the sheet. The cost of filler rods for welding Inconel will be about 4*s*. 6*d*. per lb. as an average. If a correct flame is used, no great difficulty should be encountered in the welding of even very light gauge (18 and 20 I.S.W.G.) sheets, on either one or both sides.

Flux is not essential, but can be used at the discretion of the welder.

It is again emphasized that, with all special corrosion-resisting alloys, it is imperative to clean off excess flux thoroughly after the operation is finished.

If oxidation is to be definitely obviated, a flux mixture of boric acid, borax, and sodium fluoride, or the proprietary brands now on the market can be used.

GAS WELDING

Automatic gas welding is highly successful with Inconel, and is especially suitable for making up butt-welded tubing from sheet. Such tubes are nearly as sound as seamless tubing and have the advantage of uniformity of wall section

and good surface finish. Such tubing can be annealed, drawn, swaged, and bent.

The flux mentioned in the previous paragraph should be used.

ELECTRIC WELDING

Here again, the cleanliness of the work is the first point of consideration, and as in the case of stainless steels, a short arc is desirable. Flux-coated electrodes are obtainable and good penetration can be accomplished, the molten metal being very fluid. Sufficient penetration is important, as it is desirable to grind all internal weld surfaces without impairing the general soundness of the weld as a whole.

D.C. welding is preferable to A.C. welding, and the work should be made negative.

Welding times can be taken as similar to those in ordinary mild steel.

GENERALLY

It is not proposed to tabulate prices of plant in Inconel, but as a guide to materials costs, material such as sheets, sections, and tubes can be taken from the tables of stainless steel (A. 1 quality), plus 100 per cent.

Owing to the fact that it is more easily worked than stainless steels, this percentage would not hold good for purchase costs of finished plant.

INCONEL-CLAD STEEL

A great saving in cost can be achieved by the use of Inconel-clad steel sheets, where the corrosive agent is only presented to one side of the finished article.

This covering of Inconel is rolled on to the steel plate and results in a composite plate with a strong intermetallic bond.

This method of producing composite sheets, and the correct method of fabricating such sheets follows similar lines described in the next chapter under the heading of 'Nickel-Clad Steel'.

NICKEL-CLAD STEEL

The corrosion-resisting properties of pure nickel are well known, but its capital cost operates adversely against its use, particularly in heavy plant. It is now possible to obtain mild steel plates having a layer of nickel on the side to be presented to the corrosive agent. This is not to be confounded with the method of lining steel sheets with an inner sheet of corrosion-resisting metal.

The covering of malleable nickel on one side of a mild steel plate results in a definitely composite plate with a strong intermetallic bond obtained by virtue of the heavy pressure applied in the rolls whilst the plates are at high temperature, so that in action it is nearly the equal of fusion in welding. The two slabs are put carefully through the rolls together, the thickness of each being graduated to give the predetermined finished thickness of the two metals.

After rolling in this manner the weld between them is such that subsequent operations cannot cause fracture at this weld.

The result is that a plate is provided of requisite thickness, equal in mechanical properties to a solid plate of equivalent thickness, having the corrosion-resisting

properties of pure nickel plates, but costing much less. Owing to the process of manufacture, the resulting plate is hot rolled and cannot therefore possess a bright finish like cold-rolled nickel, albeit it is equal in corrosion-resisting properties.

In view of the fact that the main function of these plates is likely to be in the manufacture of heavy plant, where surface finish is probably not the important feature, this is not really a drawback.

Another great asset of nickel-clad plates is that owing to nickel and steel possessing the same co-efficients of expansion, temperature changes do not create opposing strains.

The sheet regarded as a general standard is ¼ inch thick, the layer of nickel being about ten per cent. (0·025 inch) of the total thickness. If thinner plates were rolled, the nickel would be maintained at 0·025 inch in order to ensure a sufficient thickness for service in use as a corrosion-resisting plate.

For plates of greater thickness than ¼ inch, the nickel would be proportionately increased until in a 1-inch thick plate the thickness of the nickel would be 0·060 inch.

MANIPULATION OF NICKEL-CLAD STEEL

Cold working can be undertaken in like manner to ordinary mild steels.

Where the operation is not suitable for cold working, then plates suitably annealed can be obtained by heating to a temperature of 900° C. and cooled in air after being held at this temperature for a few minutes.

It is important to ensure that the furnace fuel contains

only the minimum of sulphur, as nickel is quickly attacked by sulphur-laden fumes. Neither should the work be allowed to be in direct contact with a strong oxidizing flame. After annealing, the oxidation on the nickel surface must be removed by pickling for several hours.

The makers advocate a pickling paste made to the following formula, this to be applied warm:

Lampblack	1 lb.
Fuller's Earth	10 lb.
Hydrochloric Acid 26° Be.	3 gallons.
Nitric Acid 38° Be.	½ pt.
Cupric Chloride	1½ lb.

RIVETED CONSTRUCTION

For tankwork of riveted construction in nickel-clad steel, the rivets used should be of pure nickel, this being necessary in order to maintain a finished tank with corrosion-resisting properties, but wherever mild steel edges are exposed, these must be protected by a weld of pure nickel.

WELDED CONSTRUCTION

The important factor is that the nickel surface must present an unbroken continuity, which means that the welding must be carried out by a pure nickel filler rod on the nickel side. In lap-welding the bare mild steel edge on the inner (or nickel) side has to be protected by a weld of pure nickel along its entire length.

Fittings on a vessel fabricated in nickel-clad plates should be of solid nickel, unless their size warrants fabricating them from nickel-clad sheets. It is emphasized again that all inner edges on such fittings must be protected by nickel.

Either oxy-acetylene, atomic hydrogen, or electric arc welding is suitable with nickel-clad plates, the latter being preferable for heavy plates. The mild steel side is welded first, nearly to the full thickness of the plate, but not running through past the nickel layer.

Following this the nickel side should be welded, and in order to make this discussion complete, we will at this stage touch upon the important points connected with correct procedure in the welding of nickel.

As with any other metal, cleanliness is of prime importance.

The metal should not be permitted to boil excessively as this will result in a brittle weld. The welds should be built up in sections to the full depth in one operation; if the layers are allowed to cool before being followed by a subsequent layer the weld is liable to be unsound.

In oxy-acetylene welding, a slightly reducing flame should be used, a flux is not necessary, but can be used if the welder so desires.

For thin sheets (say 18 I.S.W.G. or less) the edges of the sheets should be turned up for a height of about $\frac{1}{16}$ inch, this flanged part then being fused down on to the body of the sheet.

For sheets thicker than 18 I.S.W.G. the sheets should be chamfered at the joint and a filler rod of a thickness at least equal to the thickness of the sheet should be used.

In electric arc welding, which is preferable for the thicker plates, a flux-coated electrode must be used and the electrode wire should be bright soft annealed, free from oxide, and of slightly bigger diameter than the thickness of the plate.

Joints should be prepared by scarfing, on both sides if thick plates. The electrode should be positive and the work negative, whilst the arc should be very short in order to prevent oxidation.

The undesirable 'weld-decay' encountered with so many qualities of stainless steel is not experienced in nickel sheets, and as far as the weld itself is concerned, if the work is carried through as described above, it should be equal to the parent metal in its corrosion-resisting properties.

Reverting to the question of construction in nickel-clad sheets, this is particularly suitable for plant handling caustic alkalis, water storage (where it is imperative to prevent contamination by rust), soap-manufacturing plant, varnishes, peroxides, dyes, &c.

The cost of nickel-clad plates can be taken at approximately 60 per cent. of A. 1 quality stainless steel sheets given in the table on p. 17.

STAINLESS-CLAD STEEL

The preceding chapter was devoted to a discussion on nickel-clad steels, and in like manner it is now possible to procure steel plates having a facing of stainless steel, albeit the method of production is quite dissimilar.

The method of production is an American patent held by Messrs Ingersoll Steel & Disc Co., Ltd., Chicago, the trade name given to the product being 'Ingaclad'.

The material is now being manufactured and sold in Great Britain by Messrs Saml. Fox & Co., Ltd., Stocksbridge Works, Nr. Sheffield, under licence from the patentees.

The notes on the method of production are by kind permission of these two Companies.

Briefly such method is as follows:

The stainless steel, usually of an austenitic welding quality, is made up of a major portion of virgin metals poured into ingot moulds and then rolled into plates.

After rolling the plates are cleaned, ground, and cut into suitable sizes.

After proper preparation one face of each stainless plate is coated with an insulating material. The coated plates are then placed face to face and the four edges are sealed by arc welding. These two plates, thus joined, are known as an insert. The insert of stainless steel as described above is then placed in a mould. Mild steel of a special analysis is then poured into the mould, completely covering the stainless steel insert, and forming a composite ingot. The composite ingots are then rolled into plates of a pre-determined thickness. After rolling the plates are annealed to restore the austenitic structure of the stainless facing.

The four edges are then sheared back to the point where the stainless steel begins, thus producing two stainless-faced plates from each ingot.

All faced plates are then pickled and passivated to bring out the maximum corrosion-resisting qualities of the stainless steel.

It is apparent that with this cast-in-the-ingot method of production the stainless steel surface of the faced plate is not subject to roll marks, scaling, or oxidation, because the stainless surfaces are completely surrounded by an envelope of soft steel during the heating, rolling, and annealing operations. Actually the surface of the stainless facing compares favourably with a solid stainless sheet surface.

This patented method of producing Ingaclad from a

composite ingot ensures a bond between the stainless surface and the mild steel. There is no danger of the layers separating during the subsequent manipulation of the material.

Messrs S. Fox & Co., Ltd., are now producing Ingaclad plates in thicknesses $\frac{1}{8}$ to $\frac{3}{4}$ inch inclusive in the usual engineering sizes of plates.

It would certainly seem well worth while to pursue the possibilities of such plates for use in pressure vessels and tankwork generally, on the score of saving in capital costs alone.

MECHANICAL PROPERTIES

The mechanical properties of stainless faced steel are a combination of the mechanical properties of the two metals —mild steel and stainless steel—which form the combined plate. Thus the tensile strength of the stainless surface is identical with the tensile strength of a similar sheet of solid stainless steel. Likewise the strength of the mild steel is not affected by being in combination in the clad material.

CORROSION RESISTANCE

The material may be used wherever the use of a corrosion-resistant metal is desirable or practical, provided the service conditions can be met by the particular quality of stainless steel constituting the facing. It should be appreciated that the design and fabrication must be such that the mild steel backing does not become exposed to the corrosive medium. Again, it should not be used for heat applications under which the mild steel surface would be adversely affected due to oxidation, and other factors which may affect the mild steel at elevated temperatures.

FABRICATION

The fabricating of Ingaclad stainless faced steel presents very few difficulties, and may be taken, as a general rule, to behave in a similar manner to mild steel.

The fact that Ingaclad has such a large proportion of mild steel in the combined plate makes it much easier to handle in fabricating than stainless steel. Ingaclad may be punched, sheared, formed, and deep drawn, and the existing machinery for handling similar thicknesses of mild steel plates may usually be used.

In all fabricating operations care must be exercised to protect the stainless face, as scratches, embedded iron particles, &c., will affect the corrosion resistance of the stainless surface. Layouts should be made on the stainless side if possible, as this will cause die- and shear-blade impressions to appear on the mild steel side, and also eliminate the scratching of the stainless surface.

WELDING

The electric arc process is recommended for the welding of Ingaclad Silver Fox stainless faced steel.

(*a*) *Welding of stainless side.* The stainless side should be welded first, and a suitable coated electrode to lay down weld metal similar in composition to the stainless facing should be used. Reversed polarity should be employed (the electrode positive and the work negative).

The amperage used for welding the stainless steel surface should not be excessive. Too high an amperage will cause overheating in the weld area, and also of the welding electrode. Extremely low amperage will cause slag inclusions and lack of fusion. Trial welds should be made before

beginning a job, because prevailing conditions have a definite bearing on the amperage required for each diameter of electrode.

Since mild steel normally comprises 80 per cent. of the total thickness of Ingaclad, the heat is dissipated more rapidly than would be the case in like thicknesses of solid stainless steel plates, due to the relatively higher heat-conductivity of mild steel.

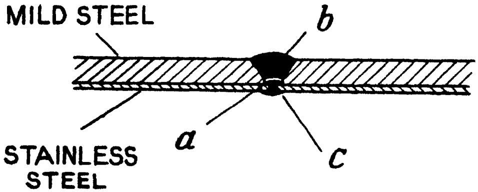

FIG. 8. Method of welding stainless steel-clad plates.

(b) *Welding of mild steel side.* In welding the mild steel side of Ingaclad plate, it is necessary to weld with multiple beads to avoid overheating of the stainless surface. It is advisable to use a high-quality mild steel coated electrode for welding the mild steel side.

Alternatively, for the heavier gauges, say ¼ inch thick and upwards, the following procedure will be found very efficient. A glance at Fig. 8 will clarify the explanation.

The plates should be chamfered where the joint is to be made, and from the mild steel side a preliminary weld (*a*) is made with a stainless steel filler rod; this is to ensure that there is no possibility of corrosion attack at the point of fusion in the composite plate.

The mild steel joint is then filled up to the full depth with mild steel filler rod (*b*). Upon completion of this main weld the stainless steel is welded on the inner side (*c*), which

should be ground afterwards in the same manner as is usual with stainless steel work.

As Ingaclad material is supplied faced with a weld decay free stainless steel, it is not necessary to heat-treat the fabricated article after welding.

ELECTRODES

The required electrode diameter for various plate thicknesses is roughly as follows:

$\frac{1}{8}$ inch for plates $\frac{3}{16}$ to $\frac{1}{2}$ inch thick
$\frac{5}{32}$ inch for plates over $\frac{1}{2}$ to $\frac{3}{4}$ inch thick.

Butt welds are to be preferred for fabricating Ingaclad material, but lap-joints may be used where found to be necessary. In the case of lap-joints, all mild steel edges in the inner side of the fabricated vessel must be protected from corrosion by a deposition of stainless weld metal.

RIVETING

Riveting as a method of joining Ingaclad material is not considered as efficient or economical as welding. In cases where riveted construction has to be used, rivets of a similar composition to the stainless steel facing must be used. Wherever mild steel edges are exposed these must be protected by a deposition of stainless weld metal.

FESCOLIZED SURFACES

Where the conditions are not too severe and the capital cost of stainless steel construction is not warranted, a good corrosion-resisting surface can be obtained by a nickel and chromium deposit known as 'Fescolizing'.

For all average requirements a nickel deposit of 0·001 inch thick, followed by a chromium deposit of 0·002 inch

thick should give good and lasting results. If desired, such a surface can be polished up to a bright finish.

Best results are obtained when the depositions are made on a hard surface, such as cast iron.

For decorative work, a nickel deposit of 0·003–0·005 inch thick, followed by a chromium deposit of ·001 inch thick will give the best corrosion-resisting qualities. Further details of this process can be obtained upon application to Messrs Fescol Ltd., 101 Grosvenor Road, Westminster, London, S.W.1.

AUSTENITIC CAST IRONS

Further to the footnote on p. 61 it is perhaps advisable to enlarge upon the reference to 'Ni-Resist'.

This is specified for the gland cocks listed, owing to the unsuitability of having two stainless steel faces together. It would be found that such faces would quickly become scored and the cocks would seize.

Ni-resist is one of a group of austenitic cast irons, and is known as a ni-chrome iron on account of the alloying elements used. In addition to Ni-resist, it might be interesting to refer to several of the other members of the group, these being chiefly as follows:

Classification	*% Carbon*	*% Silicon*	*% Sulphur*	*% Manganese*	*% Nickel*	*% Chromium*	*% Copper*
Standard Ni-resist .	3·0	1·5	0·05/0·10	1·0	12/15	2·0	5·0/7·0
Copper-free Ni-resist .	2·3	1·5	..	1·0	15/20	2·0	..
Nicrosilal . . .	1·8	6·0	..	1·0	18	2·0	..
Causal . . .	2·3	2·2	0·05	..	18/21	1·5	4·5

It will be observed that all four types have a high nickel content. This ensures that when castings are cooling in the mould they retain their austenitic properties.

These alloyed cast irons are used mainly for their marked resistance to heat and corrosion. Quite high temperatures can be obtained without the troublesome scaling always experienced with ordinary cast irons, whilst the corrosion-resisting properties are proof against a very wide range of chemicals. It is a well-known fact that chemical corrosion definitely softens a metal. What actually happens is that the matrix is dissolved, leaving unsupported graphite. The austenitic alloys provide a solid solution type of matrix and thereby offer marked resistance. On the other hand, such a matrix is only slightly affected by oxidation at high temperatures, thus providing an iron which can be used in high temperatures, such as in annealing furnaces, coke-ovens, &c.

The resistance to scaling increases with an increasing content of silicon, whilst with a decreased carbon content there is less tendency for the casting to grow.

It will be noticed that two members of the group are free from copper content. These should be used in plant where there is sodium sulphate or sulphur dyes present. Castings in these alloyed metals are much more expensive in first cost than commercial grey iron.

As a guide, it is a reasonable approximation to say that the cost of castings only would be four to four and a half times the cost of ordinary grey irons (see *The Practice of Engineering Estimating*).

The machining of such castings will not show any undue difficulty, and, in fact, might be taken at similar rates to

ordinary castings, or at most not more than 10 per cent. higher. Incidentally, the actual casting is reasonably simple and well within the bounds of the normal foundry. The increase in cost, therefore, is due mainly to the cost of the alloying elements and the greater care essential in the mixing of the 'melt'. Whilst on the question of costs, it is obviously a matter left to the jurisdiction of the engineer to determine the question of overall cost during a given period.

This again depends upon several salient features, namely, the severity of the working conditions, the amount of labour involved in site erection as compared to the purchase cost, the loss of productive time due to break-downs, and the beneficial effect or otherwise upon the product being handled.

Where the purchase cost represents practically the whole of the installed cost, that is to say, the labour on site is only a few per cent. of the total, then the frequent replacement is of such unimportance that the extra purchase cost of the alloyed metal is not warranted from this aspect.

If this is the case, then the decision rests entirely upon the beneficial results in the actual process due to possibly obtaining trouble-free running. If, on the other hand, the cost of installation is relatively high, then the initial first-cost of the alloyed metals can easily be justified over a reasonable period.

MONEL METAL

Engineers interested in corrosion-resisting alloys will undoubtedly be more familiar with Monel metal, inasmuch as it is not of such recent introduction as the other alloys discussed in this work.

It was first produced in 1905 and took its name from that of Mr. Ambrose Monell, who was President of the International Nickel Company at that time. It is a high nickel-copper alloy, the range of the analysis being as follows:

Nickel	65–70 per cent.
Copper	26–30 ,,
Iron	to 3·0 ,,
Manganese	to 1·5 ,,
Silicon	to 0·25 ,,
Carbon	to 0·25 ,,

The above range is varied to suit the particular forms of working desired, for instance, castings would have a higher silicon content (up to 4 per cent.).

The specific gravity is 8·80.

Its mechanical properties are as set out in the table on the next page.

These are superior to those of pure nickel, and also, in the case of many corrosive agents, it is also superior in its corrosion-resisting properties.

Following in the same order adopted for the other alloys already discussed, a few notes are appended relative to the various forms and the manipulation of Monel metal.

CASTINGS

The ore as obtained from the mines already contains both its nickel and copper proportions, and as these two metals are mutually soluble in all proportions, Monel metal is therefore a solid solution and the micro-structure resembles that of a pure metal. In casting, the pouring temperature is very high (about 1,540° C.) and care and experience

MECHANICAL PROPERTIES

NOTE.—Monel metal cannot be hardened by thermal treatment. Its mechanical properties can, however, be considerably enhanced by cold working, and for certain purposes it is definitely advantageous to employ it in a hard rolled or hard drawn condition. The mechanical properties of the hard rolled or soft annealed qualities in various forms are tabulated for guidance.

Type	*Condition*	*Ultimate strength* *Tons/sq. in.*	*Yield point* *Tons/sq. in.*	*Elongation* *On 4 √(area)*	*Hardness*
Hot rolled rounds, squares, rectangles or hexagons: Forgings	Normal	34–38	15–18	35%	120–140 Brinell
Cold drawn rounds or hexagons:	(A) Hard	40–45	35–40	18/20%	190–210 Brinell
Cold rolled squares or rectangles	(A) Annealed	30–35	14–17	35%	110–120 Brinell
(B) Full finish sheet	Normal	30–33	14–16	30%	18–20 Scleroscope
Cold rolled sheet or strip	(A) Hard	45–50	40–45	15%	38–42 Scleroscope
	(A) Annealed	29–30	14–16	30%	16–18 Scleroscope
Cold drawn wire	(A) Hard for springs	55–60	50–55	5/10%	..
	(A) Annealed	29–33	14–16	35%	..
Castings: normal quality	As cast	19–23	12–15	12%	110–130 Brinell
special silicon quality (*See page* 86)	Thermally hardened	38–40	22–25	10/15%	190–210 Brinell

(A) Where desired, cold rolled or cold drawn material can be produced to hardnesses intermediate between full hard and soft annealed.

(B) This grade of sheet was previously designated hot rolled but is now finished by cold rolling to give a bright surface. The sheets are flat and are recommended for moderate drawing and all bending operations.

NOTE: The above table is by kind permission of Messrs Henry Wiggin & Co. Ltd., Thames House, Millbank, London, S.W. 1, who will be pleased to give advice and further information on Monel metal and Inconel.

is very necessary. The sulphur, carbon, and silicon contents also call for experienced attention. Magnesium is added to act as a deoxidizer. The shrinkage is high, and large headers are necessary to ensure sound castings, whilst ample provision must be made for such shrinkage, which is ¼ inch per foot.

An electric furnace is used.

Cast Monel metal has the same strength range as annealed Monel metal, but with somewhat lower ductility, although this is very high compared with most cast metals. Strengths up to 45 tons per square inch are obtained with sacrifice in ductility.

FORGING OF MONEL METAL

The forging of Monel metal, like all alloys having a high nickel content, calls for particular attention to fuel and furnace conditions in order to ensure that the metal is not subjected to sulphur attack. The notes given on p. 67 relative to the forging of Inconel can be followed for Monel metal and need not therefore be repeated.

The best temperature range is between 1,040 and 1,150° C., or with care, up to 1,180° C. The metal loses all malleability at about 1,210° C. The hot ductility decreases rapidly as the temperature drops below 1,040° C., with the minimum ductility at about 760° C. Recovery for safe working is reached at about 540° C. Hot forging should not be attempted between 650 and 870° C. and only when necessary for special conditions between 870 to 1,040° C. It has higher strength at forging temperature than mild steel, and therefore requires more power.

MACHINING

The machining of Monel metal will follow on similar lines to the methods employed when machining mild steels, but high-speed tools should be used and the edge must be kept very keen. It machines with a long tough chip, the tools should therefore be ground with a positive rake and a wide clearance angle.

When machining from bars it is possible to obtain these in three distinct finishes, viz. hot rolled, cold drawn soft annealed, and cold drawn hard (strain relief annealed).

The latter is recommended by the suppliers as being most suitable for small parts, particularly for automatic or semi-automatic machining.

In *Turning* the cutting speeds may vary greatly from a slow speed of eight feet per minute, with heavy cut and feed, to a high speed of 250 feet per minute, with a small diameter and light cut and feed. A good average for general work is from 50 to 60 feet per minute, with $\frac{1}{8}$ inch cut and $\frac{1}{32}$ inch feed.

Where lubrication is necessary any good-quality soluble oil can be used.

In *Drilling* use sharp high-speed steel twist drills, the peripheral speed of the drill being kept at approximately 60 feet per minute.

Based on this figure drilling speeds for varying diameters would approximate the following:

$\frac{1}{32}$ inch diameter	7,300 r.p.m.
$\frac{1}{16}$ „ „	3,700 „
$\frac{1}{8}$ „ „	1,850 „
$\frac{3}{8}$ „ „	610 „

As explained when discussing the drilling of stainless

steels, large and hard-driven centre pops should be avoided, or undesirable work-hardened spots are presented to the drill upon commencement.

The following lubricants have been found to give the best results in the drilling of Monel metal:

Holes larger than ¼ inch diameter . . .	Soluble Oil
,, ¼ to 3/32 inch diameter	Tallow
,, less than 3/32 inch diameter . . .	Turpentine

In *Screwing* or *Tapping* the hard cold drawn condition should be obtained. It is advantageous to make allowance for the toughness of the metal. For instance, in screwing, the part to be screwed should be machined to a slightly smaller diameter than is usual for mild steel. This does not result in the production of an undersized thread since the very toughness of the metal will cause it to rise up into the 'V' grooves of the dies. This machined allowance is dependent upon the size of the work, thus, for ⅜ inch Whitworth threads, the diameter of the rod could be 0·003 inch less than is usual for mild steel. Similarly, in tapping, a slightly larger hole should be drilled than is usual in steel. As an example: in tapping a ⅝ inch gas hole, the theoretical bore of the drilled hole would be 0·811 inch, but for Monel metal a drilled hole of 0·825 inch would be preferable.

When *Milling*, the angles of the cutters should be sharper than for steel, whilst the cutting speed should be slower and the clearing spaces between the cutting-edges greater.

Staggered tooth cutters will give the best clearance in slot milling.

In *Grinding* Monel metal, it will not be found so easy to grind to very fine limits as with mild steel. The important point is to use the correct grinding wheel. A wheel which

is too hard will cause particles of metal to adhere to its face and these will prevent the breaking away of small abrasive particles, which means a clogged grinding surface.

With the correct grade of wheel, the continual removal of these small abrasive particles from the surface of the wheel constantly exposes fresh cutting-edges to the work.

The recommended wheel is a Boro Carbone C2 4K.

SOFT SOLDERING

Monel metal readily 'tins' and can be soft soldered almost as easily as copper and brass, using the same solder and fluxes.

Soft soldering is, in fact, the most convenient method of seaming Monel metal; a high or low tin solder working equally well.

HARD SOLDERING AND BRAZING

Where stronger joints or where special corrosive agents are being handled, hard soldering can be achieved quite readily.

The commercial grades of silver solders are used. Alternatively, brazing is accomplished without undue difficulty.

WELDING

As this method of fabrication very nearly follows identical lines, already discussed at some length in connexion with Nickel (p. 75), it is not necessary to repeat it here.

In oxy-acetylene welding, it can be taken as a good general rule that the burner should be one size larger than

the burner which would normally be employed in welding mild steel of equivalent thicknesses.

In electric welding, close pitch tacking (6 inch pitch) should be employed, particularly with sheets 10 I.S.W.G. and less.

It should be noted that in welded fabrication of Monel metal the welds will be practically equal to the parent metal in corrosion-resisting properties if the work has been carried out properly; neither are the belts of parent metal adjacent to the welds impaired as regards their corrosion-resisting properties.

Finally, Monel metal can be very satisfactorily used as a weld on iron castings. This can be carried out either by the oxy-acetylene or electric process, but the latter is preferable in view of the fact that the heat is much more localized and thus eliminates the need of pre-heating the casting to avoid cracking.

In conclusion, Monel metal has found a very extensive field of usefulness on account of its combined qualities of mechanical strength and corrosion-resisting properties.

Its use embraces plant handling sulphate of ammonia, pickling-plant equipment, dyeing processes, hospital and domestic appliances, aeronautical components, turbine blading, and components subjected to continuous exposure to highly superheated steam.

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